GEOCHEMISTRY OF METAVOLCANIC ROCKS AROUND ONGARBIRA, SINGHBHUM DISTRICT (BIHAR)

DISSERTATION SUBMITTED
IN PARTIAL FULFILMENT FOR THE DEGREE OF
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IN
GEOLOGY

BY
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Dedicated To My
Reverend Brother
(Mohd. Shahid)

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Reader

Date 29th June 1987

CERTIFICATE

This is to certify that the dissertation entitled, "Geochemistry of Metavolcanic Rocks around Cagarbira, Singhbhum District, Bihar", is an original work of Mr. Mohammad Abdul Wahid under my supervision and is suitable for the submission for the award of the Degree of Master of Philosophy in Geology of the Aligarh Muslim University, Aligarh. I further testify that all the data presented herein, are based on his own observations.

MZaza.
(DR. MAHSHAR RAZA)
Research Supervisor

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A. Wahid

(MOHAMMAD ABDUL WAHID)

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CHAPTER-I

INTRODUCTION

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GENERAL STATEMENT :

The Indian Shield can be broadly divided into three major units which are referred to as, Dharwar, Aravalli and Singhbhum cratons. The Singhbhum region occupying the eastern part of Indian Shield, is an area of complex geology, located in the eastern part of the Indian Peninsula approximately between latitude 21° to $23^{\circ}15'$ N and longitude 84° to $87^{\circ}30'$ E. The Singhbhum is of much economic importance on account of the occurrence of uranium mineralisation and extensive iron ore deposits. This cratonic block ranging in age from Early Archean to Late Proterozoic, is one of the earliest Archean nuclei around which the Indian Shield has grown (Naqvi, 1974). According to Mukhopadhyay in this part of Indian Shield six distinct geological provinces can be recognised (Fig. 1) which are as follows :-

1- Cratonic massif of Singhbhum Granite and Older Metamorphics.
2- Iron Ore Province of south Singhbhum, Bonai, Keonjhar, Gorumahisani, Daiteri, etc.
3- Proterozoic mobile belt of north Singhbhum and Gangpur.

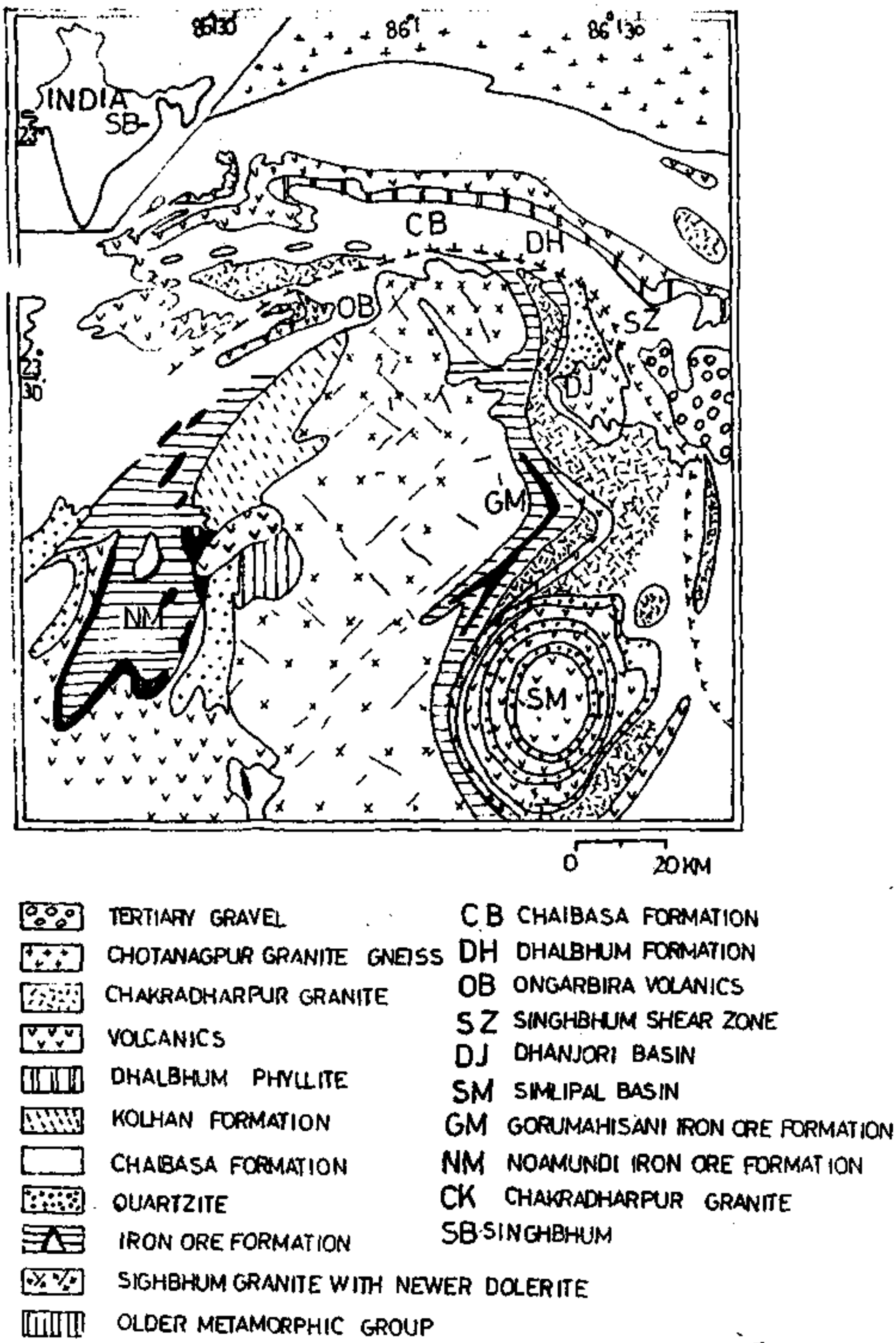

Fig.1

GEOLOGICAL MAP OF SINGHBHUM AND ADJACENT AREAS, EASTERN INDIA

4- Chotanagpur Granite gneiss massif alongwith the meta-sedimentary belts of Rajgir Mungher.

5- Granulitic terrain of northern Orissa, which is a continuation of the Eastern Ghat granulitic belt.

6- The Precambrian of Meghalaya-Assam plateau.

The existence of an old eastern cratonic block in the Precambrian tract of the Singhbhum-Orissa region was first postulated by Sarkar and Saha (1959). The Singhbhum-Orissa Iron Ore craton is a triangular region which is bounded by the Copper Belt Thrust Zone in the north and Sukinda Thrust in south (Saha, et al. 1984). The Copper Belt Thrust Zone divides the Singhbhum area into two parts, first the low grade metamorphic region in the south and second, the high grade metamorphic region in the north (Naha, 1965). The western and eastern part of the Singhbhum craton are covered by feebly metamorphosed epicontinental and platform sediments those of the western craton are much more extensive. It is assumed that the early crustal growth of the Singhbhum-Orissa Craton occurred mainly through accretion of materials, coming up along a 'sink' in the primitive proto-crust (Saha and Roy, 1984). The Singhbhum craton is dominated by a batholithic mass emplaced about 2950 Ma ago (Sarkar, 1980) and known as Singhbhum Granite. The basic volcanic rocks are associated with Singhbhum sediments and occur more abundantly in comparison to Dharwar and Aravalli areas and their distribution is markedly distinct in time and space. Large extensive outcrops of basic metavolcanics are also found in the area covering the southern part of Bihar and the northern part of Orissa (Dunn, 1929). The major basic volcanic fields of eastern India are described under the following headings.

BASIC VOLCANISM IN SINGHBHUM REGION

In eastern India the basic volcanics comprising the states of Bihar, Orissa and West Bengal, are found mainly in Singhbhum, Keonjhar, Mayurbhanj and Sundergarh districts.

In Singhbhum district the ultrabasic rocks occur in the Precambrian terrain as transcutting dykes, concordant lenses and irregular masses. A survey of existing publications suggests that the earliest groups of ultrabasic rocks are intrusive into the rocks of Iron Ore Group and were emplaced before the Singhbhum granite. The younger group is intrusive into Singhbhum granite and less metamorphosed compared to the earlier groups. Extensive investigations of different aspects of the ultrabasic rocks have been carried out from time to time. The important basic volcanic fields of eastern India are as follows :-

1- The Bonai range volcanic rocks in Keonjhar and Sundergarh districts, Orissa.

2- The Ukam Pahar - Gorumahisani volcanic rocks in Singhbhum and Mayurbhanj districts.

3- The Dhanjori volcanic rocks along the southern fringe of Singhbhum copper belt, Bihar.

4- The Dangoaposi volcanic rocks near Noamundi, Singhbhum district, Bihar.

5- The Dalma volcanic rocks in Singhbhum district, Bihar.

6- The Ongarbira volcanic rocks in Singhbhum district, Bihar.

The Ongarbira volcanics of present study occur with Sahedba sedimentaries and have been correlated with Dhanjori, Dalma and Jagannathpur lavas (Banerjee, 1982) which are of Middle Proterozoic in age (1700-1600 Ma. Sarkar and Saha, 1977).

Since the birth of the plate tectonics, the study of mafic and ultramafic rocks have been given prime importance to solve many geological problems (Kroner, 1981). In this regard the basic and related rocks of Singhbhum region may be considered to be of great importance. Over the last two decades a number of geochemical studies have been made on older volcanics with the aim to identify their eruptive environment and its relationship with composition of basic rock generation (Chayes, 1964; Engel et al., 1965; Dickinson and Hathurton, 1967; Pearce and Cann, 1971, 1973; Jakes and White, 1972; Ninkovich and Hays, 1972; Pearce et al., 1975, 1977). The secular changes in chemistry of basic rocks may reflect the evolution of upper mantle and crust with time. The similarity in composition and in age of some Precambrian igneous rocks and lunar rocks (e.g. Anorthosites) allows a comparative study in order to understand the planetary development (Windley,1970; Morgan et al., 1976; Naqvi and Husain, 1979). In all these respects the Precambrian mafic and ultramafic rocks of Indian Shield have a global importance. Geochemical and petrological studies have been proved very useful in correlation between magma composition, the depths of their formations, and physico-chemical conditions of upper mantle (Kuno, 1959, 1966; Yoder and Tilley, 1962; Ringwood, 1966; Kushiro, 1969; Green and Ringwood, 1972; Nicolls and Ringwood, 1972). In recent years the attention of Indian scientists has been focussed on the Singhbhum district and efforts for geochemical studies are being made. No systematic and detail study of these basic rocks has been done so far. The present work is an attempt to study the geochemistry, petrography and mineralogy of the part of Singhbhum metabasics (Ongarbira volcanics).

LOCATION OF STUDY AREA :

The work area lies about 13 km northwest of Chaibasa town (Singhbhum district, Bihar). Its location is approximately at 42°30' N Longitude and 34°30' E Latitude. Barkela village is very near to study area.

ACCESSIBILITY :

To get at the study area both train and bus are used. Up to Jamshedpur we can reach easily by train and from there to Chaibasa as well as Barkela the bus services are frequent.

TOPOGRAPHY :

The area is not a flat terrain. There are rugged hills and the maximum height of the hill (Ongarbira hill) is 2137 feet while minimum height is 750 feet. The map area of basic volcanic rocks is sickle shaped, its width of exposure is maximum on and near the apparent closure.

CLIMATE :

In this area there is fluctuation in climate, as the hottest months are May and June and the highest temperature recorded during these months is approximately 42°C while in winter season the coldest months are December and January during which the recorded minimum temperature is approximately 22°C. There is intermittent rain from July to September due to north-eastern monsoon of Bengal.

PURPOSE OF WORK

The present investigation has been planned after reviewing carefully the previous work relating to geochemistry of basic rocks in Singhbhum district, Bihar. The purpose of present work, as carried out by the author, has been to study the geochemistry and petrography of the study area.

The purpose of present geochemical study is an attempt to determine the nature of magma type, its genesis, nature of the source area and its environment of eruption and significance in interpretation of regional tectonics. For the purpose the major and trace elements analyses of Ongarbira volcanics have been carried out. The work has been presented in various chapters as described below.

In the second chapter the geology of the area with field characteristics of Ongarbira volcanics has been discussed.

Third chapter deals with petrography including microscopic characteristics of Ongarbira volcanics.

Chapters fourth and fifth are dealt herewith major and trace elements distribution and their magmatic relationships.

In the sixth chapter major and trace element compositions have been used to elucidate the genesis and evolution of these rocks. Geochemical clues are used to interpret the environment of eruption of these volcanics as discussed in the seventh chapter.

A summarised and concluded account of the study has been presented in the end.

PRESENTATION OF THE WORK

FIELD INVESTIGATIONS :

A survey of various outcropping rock type was conducted in the field area and about 50 samples were been collected, out of which the most fresh and unweathered samples were selected for geochemical studies.

LABORATORY INVESTIGATIONS :

Chemical analyses, petrographic and mineralogical studies undercome the laboratory investigations.

PRESENTATION OF RESULTS :

After chemical analysis, the data of various major and trace elements have been plotted in different variation diagrams. The analytical results are presented in different tables.

PREVIOUS WORK

Ball (1881) laid down the foundation of Singhbhum geology. Later on Dunn (1929) during the course of his work in northern Singhbhum studied the stratigraphic succession, and observed if the Ongarbira rock mass were a series of flow then it would be correlated with Dalma traps. This was later contradicted by Sarkar and Saha (1963) who found two contrasting orogenic belts in this region. They placed the Ongarbira volcanics within the Iron Ore Group. Gupta et al. (1980) following Dunn, opined that the Ongarbira volcanics might be a distanded part of Dalma traps but later on they contended their approach (Gupta et al., 1981) and placed these volcanics within the Iron Ore Group. This work was not enough to solve the problem of stratigraphic correlation. Banerjee (1982) studied the area in detail and correlated these volcanics with Dhanjori, Dalma and Jagannathpur volcanics. He has also given some geochemical data to indicate the geochemical similarity between these volcanics.

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CHAPTER-II

GEOLOGICAL SETTING

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GENERAL GEOLOGY AND STRATIGRAPHY :

Singhbhum is an area of complex geology which tectonically has been divided into three zones, i.e. Singhbhum craton in south, Orogenic belt in centre and Chotanagpur granite-gneiss terrain forming a plateau in the north (Sarkar, 1982).

The general stratigraphic succession of Singhbhum was first proposed by Dunn and Dey (1942). Later, Sarkar and Saha (1963) modified it and suggested the existence of two intersecting orogenic belts in this region. Further, on the basis of intense structural and stratigraphic studies, supplemented by K-Ar, Rb-Sr, and Pb isotopic data, Sarkar and Saha (1963, 1977 and 1983) and Sarkar et al (1967, 1968 and 1969), have established the presence of three distinct orogenic cycles with closing dates at 3200, 2950 and 850 Ma respectively and proposed a revised stratigraphic succession of Singhbhum region as follows :-

Stratigraphic Succession of Rocks in
Singhbhum and the surrounding areas.

(after Saha, 1977)

Alluvium

Tertiary Gravel

Laterite

Baripada Beds

------------------------ End of Singhbhum Orogenic Cycle (850 Ma)

Newer Dolerites (1600-950 Ma)

Mayurbhanj Granite (1200 Ma)

Biotite Granite Gneiss, Granophyres, Soda Granite (1500-1100 Ma)

Chakradharpur Granite-Gneiss, Kuilipal Granite, Nilgiri Granite-Gneiss (1500-1100 Ma)

Anorthosite-Gabbro (1470 Ma) with pyroxinite and piorite-peridotite ultramafic intrusions.

Kolhan Group (1600-1500 Ma) Quartzite, Conglomerate, Limestone and Shale, etc.

Dhanjori Group (1700-1600 Ma) Dalma-Dhanjori-Simlipal-Jagannathpur lavas alongwith quartzite, conglomerate

----------------------- Unconformity -----------------------

Dhalbhum Stage Singhbhum Group (2000-1700 Ma) Chaibasa Stage	Mica Schist, Ortho-quartzite Schist, Shale, Hornblende Schist, Calc-chlorite Schist, Biotite Muscovite Schist, etc.	Gangpur Group Conglomerate Quartzite, Shale, Phyllite, Sandstone, Dolomite, Marble, Limestone, Slates, etc.

----------------------- Unconformity -----------------------

Singhbhum Granites (2950 Ma)	Mainly Biotite Granodiorite, Adamellite, Hornblende Granodiorite, Diorite, etc.
---------------- Iron Ore Orogenic Cycle ----------------	
Iron Ore Group	Upper Shale, Volcanics, Shales, BHJ/BHQ, Lower Shale, Mafic Lavas, Orthoquartzites, Conglomerate, Sandstone alternating with Phyllites.
---------------- Unconformity ----------------	
---------------- Older Metamorphic Cycle ----------------	
Older Metamorphic Gneiss (3200 Ma)	Banded Amphibolites as such in the Singhbhum Granite, Banded Cata-Gneiss, Mica Schist, Quartz-Schist, Tonalite, Granite Gneiss.
Older Metamorphic Group	
Basement 3300 Ma.	

Sarkar and Saha (1977) on the basis of their structural and stratigraphic studies around Chaibasa area in Singhbhum region, have given the following stratigraphic sequence.

Chakradharpur Granite Gneiss	
Singhbhum Orogeny	(C. 1550 - 850 Ma)
Newer Dolerite	(C. 1600 - 950 Ma)
	Jojuhatu Ultrabasic Intrusive
Kolhan Group (C. 1500 - 1600 Ma)	) Shale)) Limestone) Sandstone) Conglomerate

---------------- Unconformity -----------------

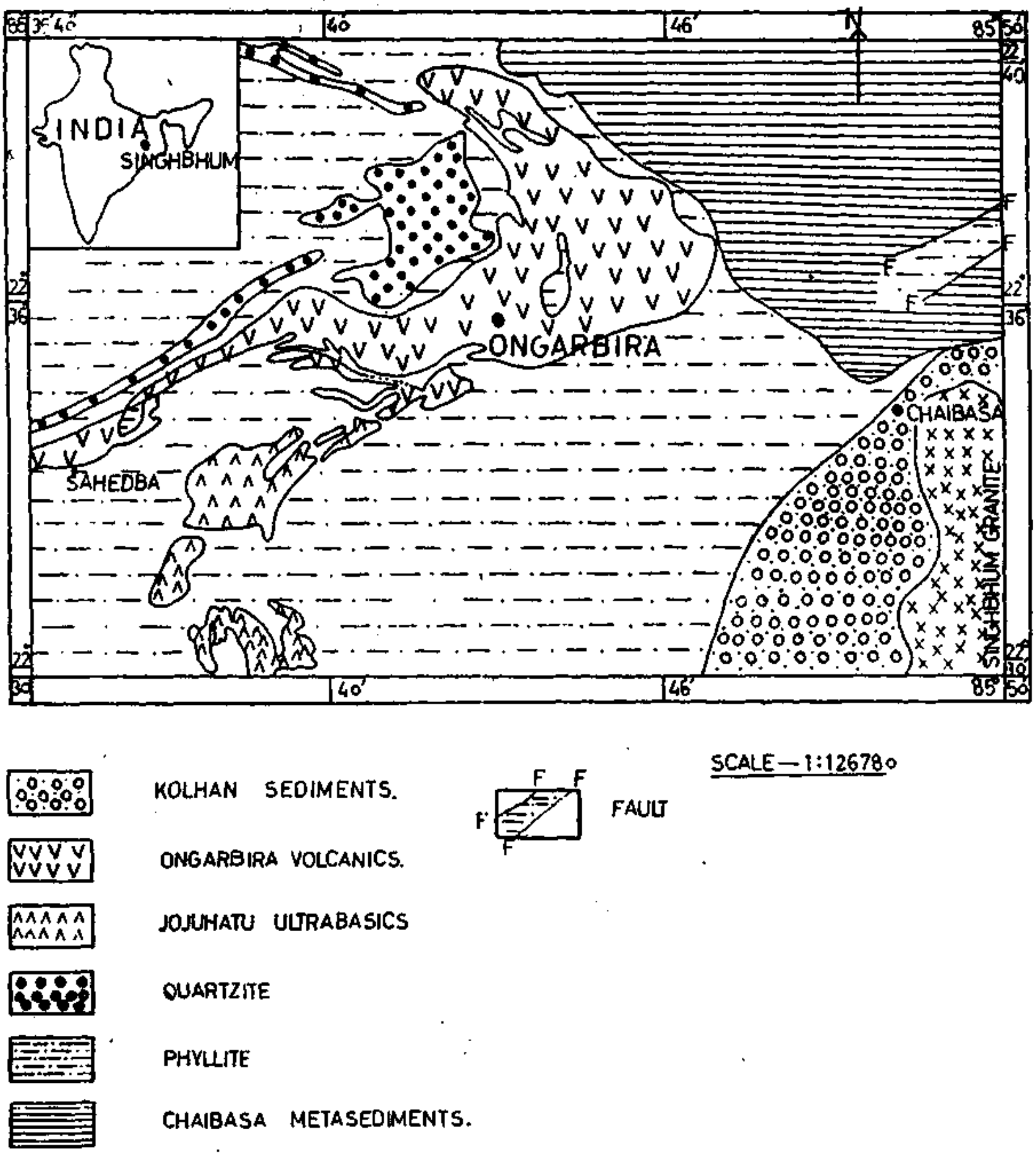
Singhbhum Granite (C. 2950 Ma)

-------------- Iron Ore Orogeny ----------------

Iron Ore Group	(Phyllite with volcanics ((Quartzite ((Phyllite ((Ongarbira lava flow ((Several bands of orthoquartzite (with minor arkose and conglom- (erate alternating with phyllite.

---------------------- Unconformity --------------------------

Older metamorphic banded gneiss and amphibolite (related to older metamorphic orogeny) as relics within Singhbhum Granite.



SIMPLIFIED GEOLOGICAL MAP OF THE AREA (AFTER BANERJEE, 1982)

Fig.2

In this succession the position of Ongarbira volcanics is much clear. According to these authors (op. cit.) the Ongarbira volcanics occur as flow within the Iron Ore Group. However, Banerjee (1982, Fig. 1) during his work around Ongarbira area, found that these volcanics are associated with a sequence of shale, phyllite, quartzite and some patches of limestones, named as Sahedba Formation which unconformably overlies the rocks of Chaibasa stage.

Banerjee (1982), on the basis of detail studies on the stratigraphic succession in Chaibasa and Ongarbira areas, proposed the following stratigraphic sequence :-

Kolhan sedimentaries

Ongarbira metabasic rocks

Sahedba sedimentaries

Goilkera-Kharswan-Kendra metamorphites (Chaibasa stage).

In the Ongarbira area the lowermost lithologic unit, predominently consists of impersistent quartzite with schist and phyllites, form the rock sequence of Chaibasa Stage which is underlain by basement granites (c.f. Iyenger and Murthy, 1982). The quartzites are often found with current bedding and ripple marks.

The Sahedba Formation which consists of a sequence of shale, phyllite and quartzite with local patches of limestone (Banerjee, 1982) conformably overlies the rocks of Chaibasa Stage. The Ongarbira volcanics are associated with Sahedba sedimentaries. These volcanics are folded, faulted and at some places have been metamorphosed into green schist facies. They are generally greenish grey in colour, fine to medium grained with occasional occurrence of large vesicles and pillow structures.

The Kolhan Group is consist of shales, sandstones and limestones and unconformably overlies the Sahedba Formation. The unconformity between Sahedba and Kolhan Formations clearly indicates that Kolhan is younger than Sahedba Formation.

AGE AND CORRELATION :

Dunn (1929) working in northern Singhbhum observed if the Ongarbira rock mass were a series of flow than it would be correlated with Dalma traps. In an attempt to correlate the Ongarbira volcanics with Dalma lavas, Gupta et al. (1980) and Sarkar (1982) suggested that the basic volcanics in Ongarbira area perhaps represent the distanded extension of Dalmas. The correlation between Dalma, Dhanjori, Jagannathpur and Simlipal lavas with 1700-1600 M.a has been suggested by Sarkar and Saha (1977, 1983).

Banerjee (1982) has suggested that Ongarbira vulcanicity is associated with rocks of Sahedba Formation, which is younger than Nonai Iron Ore Group and equivalent to the sixth sequence of Rao et al (1964), comprising low dipping shales, phyllites and calcareous rocks, etc. with contemporaneous eruptions of lava and tuff. In this area the Sahedba sedimentaries conformably overlie the rocks of Chaibasa Formation which is clearly revealed in Sanjai river section 400 m on either side of the road bridge connecting Chakradharpur with Chaibasa. The angular unconformity between Sahedba and Kolhan sedimentaries is prominent in the nala, northwest of Chaibasa town and therefore, indicates that the Kolhan metasediments with 1600-1500 Ma (Sarkar and Saha, 1977) are younger than the Sahedba sedimentaries. On the basis of these field relations the Ongarbira volcanics have generally been considered as the equivalent of Dalma, Dhanjori, Jagannathpur, and Simlipal lavas with 1700-1600 Ma.

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CHAPTER-III

PETROGRAPHY

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The Ongarbira volcanics are grey to greenish in colour, fine to medium grained and very hard in nature. They are generally unaltered but at places have suffered metamorphism up to the grade of green schist facies which is indicated by the presence of secondary minerals viz., amphiboles, chlorite, calcite, etc. Mineralogically, Ongarbira volcanics are composed of primary magmatic minerals like pyroxenes with small amount of plagioclase and opaques. The altered metabasics contain the secondary minerals like chlorite, calcite and quartz. The principal minerals of Ongarbira volcanics show the following petrographical characters.

PYROXENE :

In the Ongarbira volcanics augite forms phenocrysts as well as ground mass. The crystals of augite, euhedral to subhedral in forms, exhibit one set of cleavage and the polarisation colours are yellow and brown.

PLAGIOCLASE :

Plagioclase is albite in composition (An_{20} to An_0) with extinction 3^o to 5^o, forms less phenocrysts and more ground mass. Mostly the plagioclase show lameller twinning. Some laths of plagioclase display the **subophitic** texture with pyroxene.

AMPHIBOLE :

Actinolite variety of amphibole is the major constituent of Ongarbira volcanics in some samples, occurs as long prismatic phenocrysts as well as columner to fibrous aggregate in ground mass. The laths of actinolite are parallel to sub-parallel. They are pale green in colour in plane polarised light and possess high second order colours (green) under cross nicols.

CHLORITE :

Chlorite, greenish in colour, occurs as secondary mineral in Ongarbira metabasics. The flakes of chlorite which occupy the space in the matrix only, are very rare.

CALCITE :

Calcite occurs as secondary mineral which occupies the ground mass only. They are rhombed in shape with no perfect cleavage.

QUARTZ :

This is the secondary mineral which occurs as accessory mineral. It is medium to fine grained with anhedral form. The secondary quartz grains are also present in veins.

OPAQUES :

In Ongarbira volcanics, opaque minerals are magnetite and ilmenite. Their crystals are euhedral to subhedral and disseminated throughout the thin sections. The skeletal crystals of ilmenite occur frequently.

TEXTURES :

The Ongarbira volcanics are generally holocrystalline. The large-elongated and needle shaped crystals of actinolite are parallel to sub-parallel in orientation with little plagioclase in the ground mass. They display an important quench texture and give an appearance of micro-spinifex texture which is characteristic feature of basaltic komatiites.

Another important textural relationship is found between microlites of plagioclase and pyroxene. The microlites of plagioclase appear to enclose partially the pyroxene crystals and give the appearance of sub-ophitic texture.

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CHAPTER-IV

MAJOR ELEMENT GEOCHEMISTRY

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GENERAL STATEMENT :

The major elements make up about 99 per cent of the earth crust and mantle and their concentrations appear to be relatively well established in the upper mantle. The study of major element concentrations and their oxides is more important as it gives an idea about the distributional pattern of the elements during the crystallisation of magma. The distribution of major element oxides e.g., Al_2O_3, Na_2O and Fe_2O_3 show a regular distributional pattern. While MgO, K_2O and FeO, display less regular distributional pattern. The concentration of silica is statistically controlled by some strict rules (Barth, 1962). It has been observed that the rocks with high silica contents are usually high in alkalies, low in lime and magnesia while the rocks with low silica contents are high in lime and magnesia and low in alkalies. Among the major oxides SiO_2 exhibits wide range of variability and is used as independent parameter, while the other oxides with small range of variability are used as dependent parameters. The relative concentrations of major elements in basic volcanic rocks help in deducing the nature and the tectonic environment, existed at the time of their eruption (Gilluly, 1971; Pearce et al., 1975, 1977; Mullen, 1983). They are also proved to be helpful in determining the physico-chemical conditions at the time of magma crystallisation

In the present study nine samples of Ongarbira volcanics have been analysed. The analytical techniques are discussed in the following paragraphs. The major element compositions and their plots in various variation diagrams are discussed in this chapter.

ANALYTICAL TECHNIQUES :

Large number samples of Ongarbira volcanics have been collected out of which nine fresher and unweathered representative samples were selected on the basis of microscopic examination for geochemical studies.

Major, minor and trace elements were analysed according to modified procedure of Shapiro and Brannock (1962).

The rock samples were powdered to about 400 mesh and two types of solutions 'A' and 'B' were prepared for the analysis of major oxides as well as minor and trace elements.

Procedure for Preparation of Solution 'A' :

Solution 'A' was used to determine silica and alumina. In present study, following procedure is adopted.

1- Transferred 5 ml portion of 30 per cent NaOH in a nickel crucible.

2- Evaporated the solution to dryness.

3- Accurately weighed 0.5 gm of the rock powder directly in a crucible and transferred to pellets of NaOH into it.

4- Covered and heated the crucible to dull redness then allowed the melt to cool.

5- Added about 50 ml distilled water to each crucible, covered it and kept undisturbed overnight.

6- Transferred the contents of each crucible to 500 ml beaker and added 20 ml of 1 : 1 HCl + about 5 ml to 8 ml aquaregia.

7- Placed the beaker on a hot plate and the solution was boiled for ten minutes till a clear solution was obtained.

8- Transferred the solution of beaker to one litre volumetric flask (previously rinsed with 1 : 1 HCl).

9- Diluted each solution up to mark and mixed well and transferred it into plastic bottles.

Procedure for Preparation of Solution 'B' :

Solution 'B' was used for the determination of MnO, Fe_2O_3, MgO, CaO, TiO_2, Na_2O, K_2O, Ni, Cu, Co, Zn, Cr, Li and Sr.

1- Took 0.1 gm rock powder in taflon bombs and added 3 ml HNO_3 and 4 ml HF.
2- Kept the bombs in a heating block (at temperature 130°C-140°C) and kept for three hours.
3- Removed the bombs from heating block and cooled them at room temperature.
4- Added 5.68 gms of boric acid in a flask of 100 ml, transferred taflon bomb solution in same flask, wait till the boric acid is dissolved then made up to mark.
5- Transferred into plastic bottles.

Determination of Various Constituents :

The Al_2O_3 and SiO_2 were determined by the spectrophotometer by developing coloured ions of the respective elements and measuring their absorbance in the following selected wave lengths.

Major Oxides	Wave Length	Silt width	Colour
SiO_2	640 mμ	0.12	Red Sensitivity
Al_2O_3	475 mμ	0.90	Blue Sensitivity

For eliminating error due to possible 'reagent contamination' a reagent blank was set-up with distilled water for each set of determination. The TiO_2, Fe_2O_3, MgO, CaO, Na_2O, K_2O, P_2O_5 and MnO and trace elements, Cu, Zn and Li have been determined by Atomic Absorption Spectrophotometer (Perkin Elmer 5000) from 'B' solution while the other trace elements, Ni, Cr, Co, Ba, Rb and Sr have been obtained by Atomic Absorption Spectrophotometer (Perkin Elmer, HGA-400). FeO was separately determined by titration method.

All analysed data have been standardized against standards BM and AGV-1.

BULK CHEMISTRY :

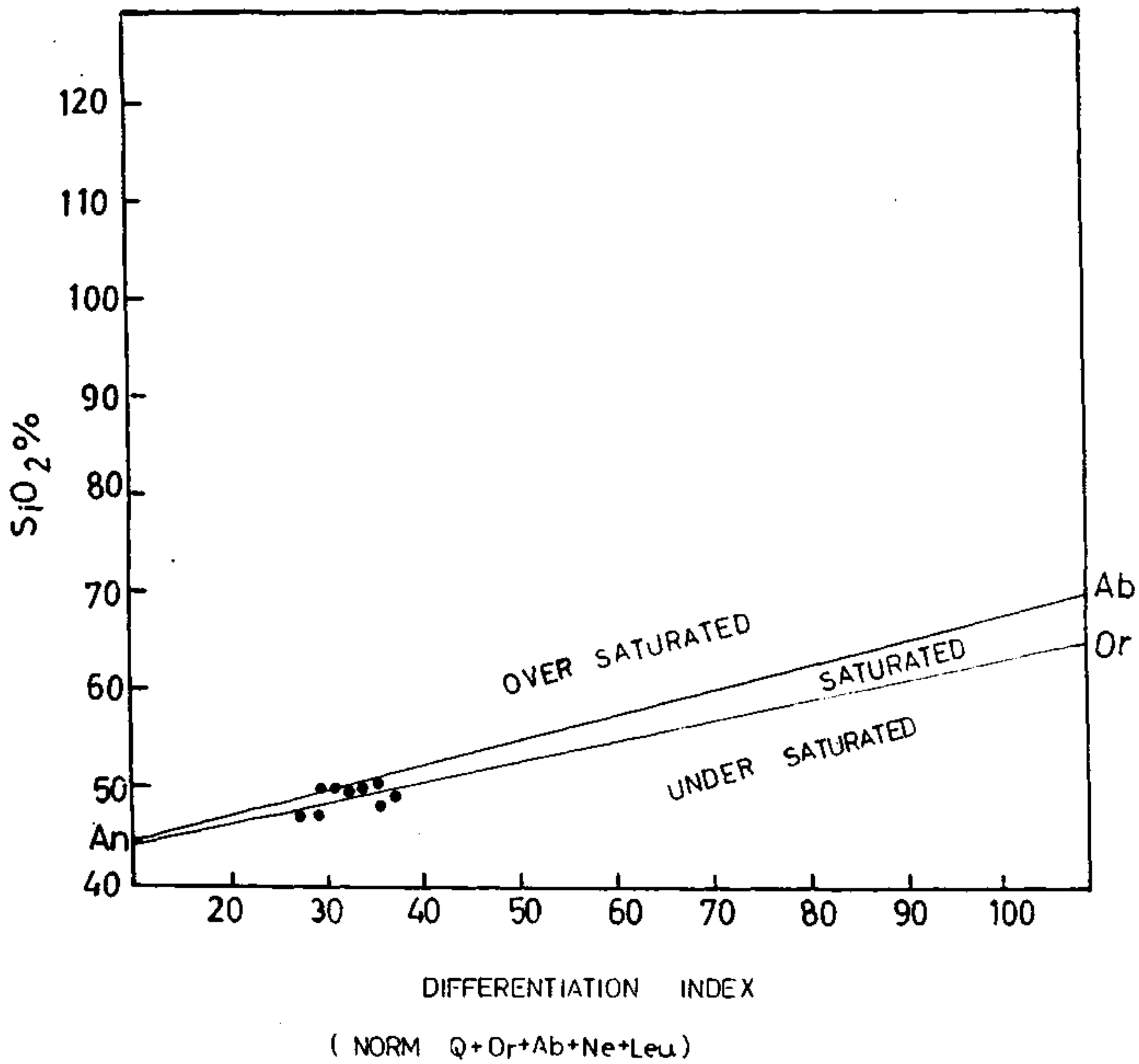
The major element compositions, along with normative compositions, petrochemical calculations and some important oxide ratios, are presented in Tables-I and II and discussed as follows.

Silica which has a great importance in determination of rock types, ranges from 45.30 to 51.05 per cent with an average value of 48.95 per cent. The concentration of Al_2O_3 varies from 9.98 to 11.40 per cent and averages at 10.75 per cent. The range of variation of Fe_2O_3 content is between 0.75 and 6.90 per cent having an average value of 2.66 per cent. The FeO has relatively high values, ranging from 7.52 to 11.08 per cent with an average value of 9.22 per cent.

Na_2O content of these rocks appear high, ranges between 3.35 and 6.25 per cent and averages at 4.56 per cent. Higher values of Na_2O in some samples indicate their spilitized nature, on the other hand K_2O content is low and show a range of variation from 0.07 to 0.19 per cent with an average of 0.16 per cent.

MgO content in these rocks appears fairly high and varies from 8.20 per cent to 11.78 per cent and averages at 9.59 per cent. CaO content is also higher and varies from 8.43 per cent to 13.38 per cent and averages at 11.54 per cent. The TiO_2 content which provides a great discriminating power among the major oxides of basaltic rocks (Chayes, 1964) ranges from 0.84 per cent to 1.41 per cent with an average value of 1.21 per cent. P_2O_5 concentration varies from 0.24 per cent to 0.42 per cent and averages at 0.318 per cent.

The average SiO_2/MgO and FeO^*/MgO ratios of these rocks appears as 5.17 and 1.11 respectively. The low values are probably because of their high MgO contents. Fe_2O_3/FeO ratio plays an important role in distinguishing the alkalic and tholeiitic basalts. The proposed values of Fe_2O_3/FeO ratio for alkaline and tholeiitic basalts are 0.5 and 0.3 respectively (Kuno, 1959). Seven out of nine samples of Ongarbira volcanics indicate their tholeiitic nature when Fe_2O_3/FeO ratios are taken into consideration. The CaO/Al_2O_3 ratio, which has been used by Brooks and Hart (1974) and Arndt and Nisbet (1982) as an important criterion in distinguishing



DIFFERENTIATION INDEX PLOT FOR ONGARBIRA VOLCANICS.

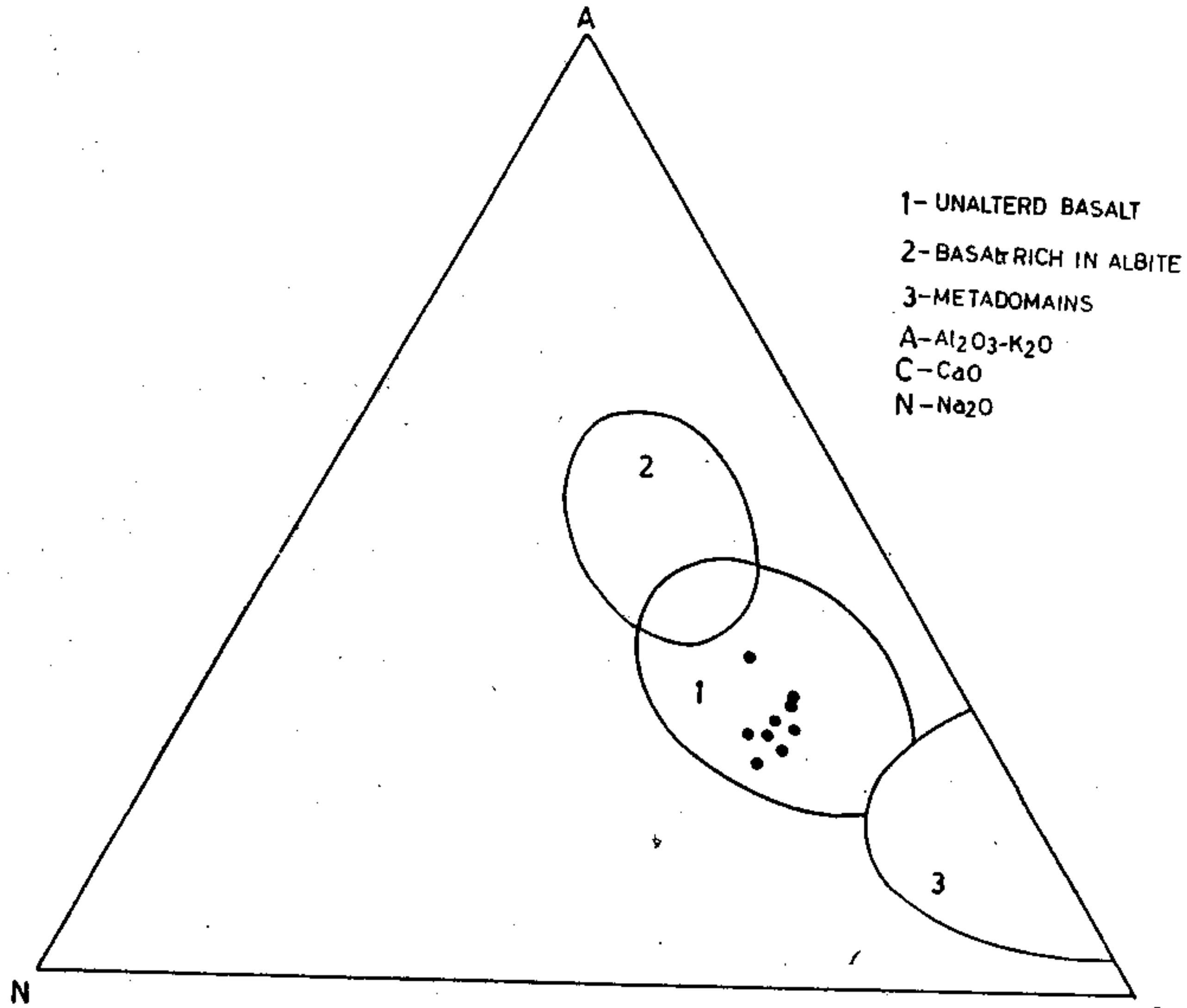
Fig.3.

Komatiitic rocks varies from 0.80 to 1.28 with an average of 1.07.

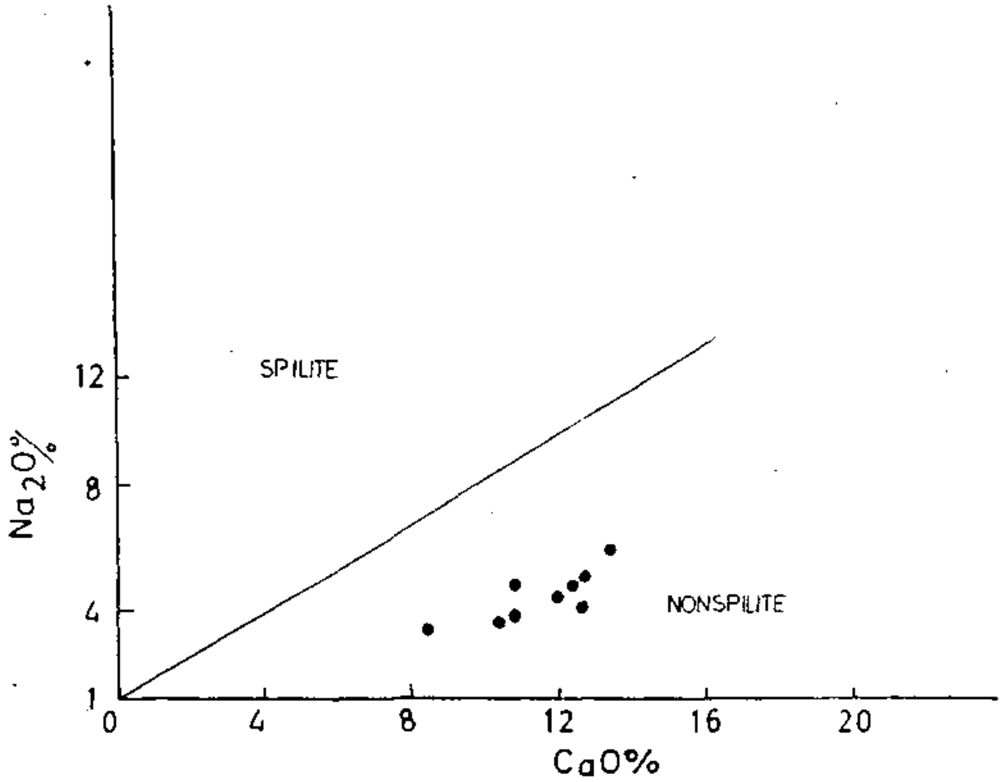
Normatively, these rocks possess very very less amount of quartz which indicates just saturated to undersaturated nature. This is also evident by the plot of differentiation index (normative Q + Or + Ab + Ne + Le) versus silica contents (Fig. 3) of Thronton and Tuttle (1960). About 77 per cent samples are nepheline normative and rest 23 per cent have hypersthene in their norms. The average normative assemblages consist of about 22.70 per cent sodic plagioclase (albite), 8.4 per cent calcic plagioclase (Anorthite) and 11.82 per cent olivine. The average diopside content appears as 37.97 per cent and shows its presence in all samples. Magnetite, ilmenite, and apatite are present normatively in these metabasics with averages 2.44 per cent, 2.33 per cent and 0.78 per cent respectively.

EFFECT OF ALTERATION :

The alteration effect if any, is of much importance in geochemical studies of older volcanics, because the abundance of various elements resulted from magmatic melts can later be modified by metamorphism, metasomatism or by subsequent weathering. In studies of older lavas it is important to know the effect of alteration on rock chemistry before any interpretation is made. In recent years several techniques are



A C N, PLOT FOR ONGARBIRA VOLCANICS. Fig. 4.



CaO— Na_2O, PLOT FOR ONGARBIRA VOLCANICS

Fig.5.

being employed to make the alteration effect studies easy, in which the most common approach is to choose the most fresh rock which may be least altered or unaltered and the composition of these unaltered rocks are then used as a basis for chemical comparison with more altered rocks (Babcock, 1973; Condie et al., 1977; Sun and Nesbitt, 1978).

Several variation diagrams and chemical criteria have been used herein to see the effect of alteration on the rock composition of Ongarbira volcanics which has suffered low grade metamorphism.

Plots of Ongarbira volcanics in the ACN diagram of Jolly and Smith (1972) brings out the exact compositional changes which took place in the post-eruption period. The Al_2O_3-K_2O, CaO and Na_2O constituents of Ongarbira volcanics have been plotted in this ternary diagram (Fig. 4) which because of high CaO contents appear in the field of unaltered basalts with slight inclination towards the sodium apex, but within the enclosed field though these rocks are enriched in Na_2O. The non-spilitic nature is also evident in Na_2O versus CaO plot (Fig. 5) of Vallencio (1974) because of high CaO content in these rocks, though they have high Na_2O content and appear spilitic.

To see the post igneous changes in concentration of some elements of petrogenetic importance, a graphical method has been suggested by Beswick and Soucie (1978) and Beswick (1982) is used herein.

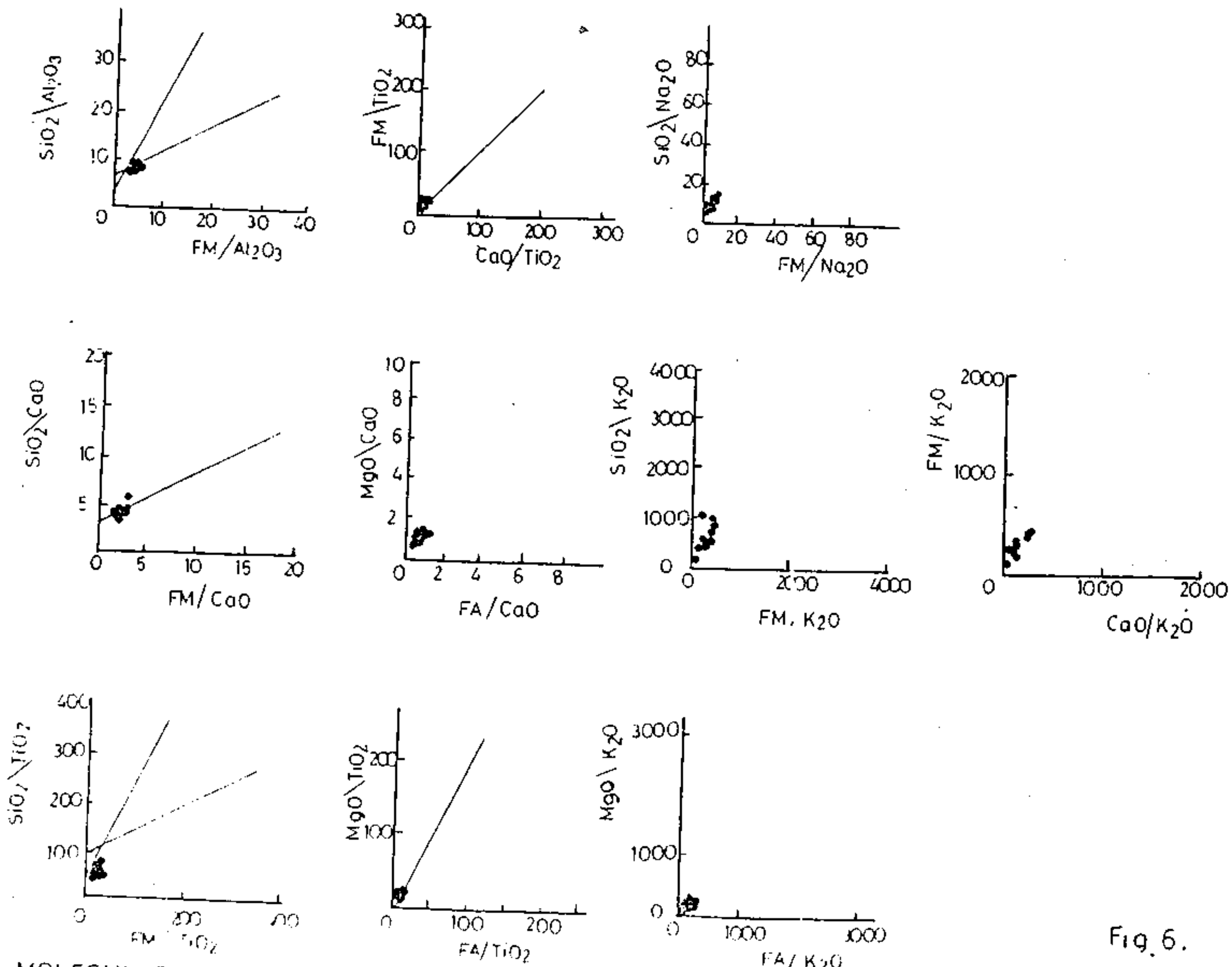
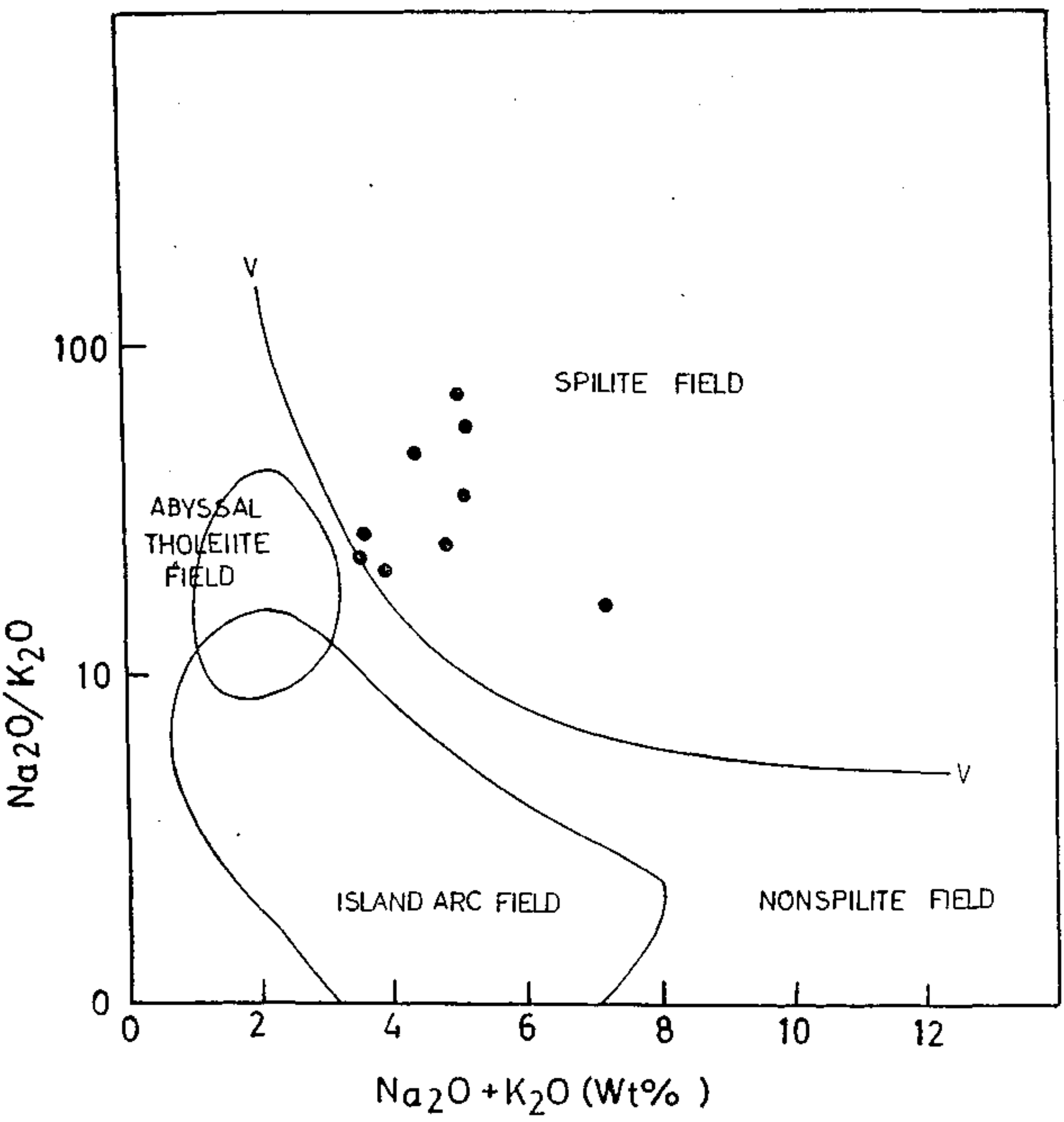


Fig. 6.

MOLECULAR PROPORTION RATIO(MPR) PLOTS FOR ONGARBIRA VOLCANICS.



$Na_2O/K_2O - Na_2O+K_2O$ PLOT FOR ONGARBIRA VOLCANIC.

Fig.7.

Following this procedure, the molecular proportions of SiO_2 and FM($FeO^* + MgO$) of Ongarbira volcanics are plotted against each other in figure-6. These both oxides are normalised to various oxide proportions in different plots. The fan shape distribution of points radiating from the origin in different plots, significantly shows mobilization of elements, while clustering of the points indicates immobilization of the elements. In the present study most of the elements, plotted in these diagrams, show a cluster near the origin, except Na_2O and K_2O contents (weight per cent) of Ongarbira volcanics are plotted (Fig. 7) in Na_2O/K_2O - $Na_2O + K_2O$ variation diagram of Miyashiro (1975), they appear as spilitized.

The spilitic nature of Ongarbira volcanics has also been evidenced by low K_2O and high Na_2O contents compared with average basalts, and by apparent coexistence of albite, chlorite, and augite (Yoder, 1967).

On the basis of above discussion it may be suggested that the Ongarbira volcanics have suffered spilitization resulting in enrichment of Na_2O. It also appears that other major elements have not suffered much mobilization and therefore, may be used in petrogenetic interpretation. However, author has tried to use only those elements which are less mobile during secondary processes.

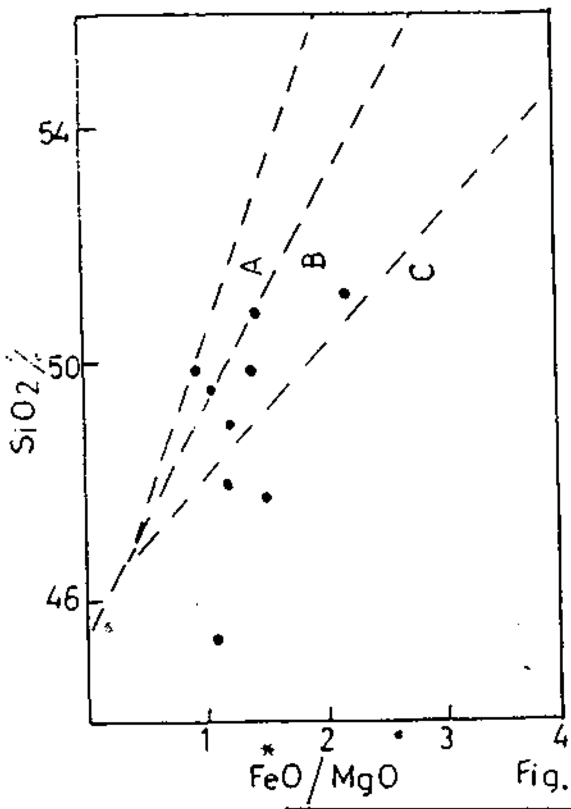


Fig.8

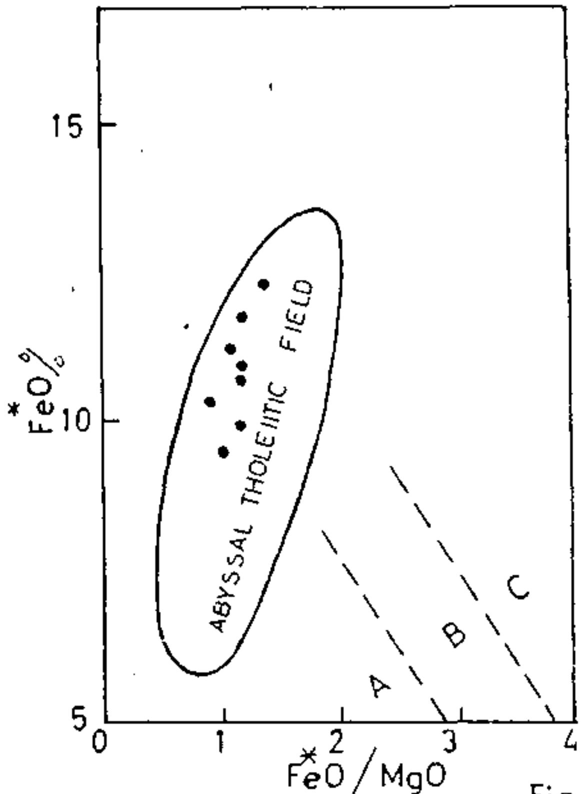
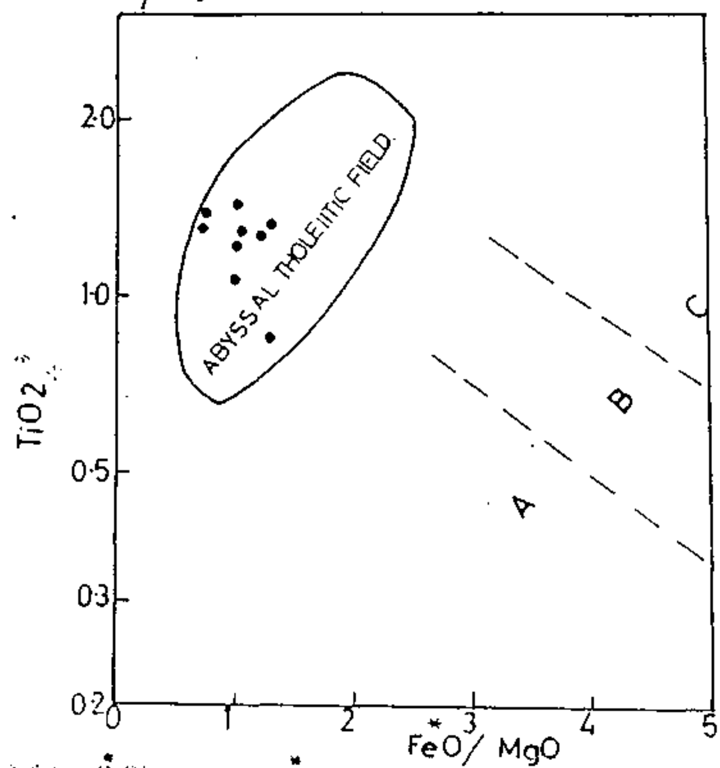


Fig.9.



A CALC ALKALINE SERIES

B THOLEIITE AND CALC-ALKALINE SERIES

C THOLEIITE SERIES

Fig.10.

FeO*/MgO-SiO2, FeO*/MgO-FeO*, FeO*/MgO-TiO2 PLOTS FOR ONGARBIRA VOLCANICS.

MAGMA CLASSIFICATION :

To distinguish the magma types, the alkali-silica diagram (Kuno, 1959; McDonald, 1968) and AFM (A = $Na_2O + K_2O$, F = Total iron as FeO, M = MgO) diagram (Nockolds and Allen, 1953; Coombs and Wilkinson, 1969; Irvine and Baragar, 1971) have been in use for many years. These diagrams are predominantly based on alkalies and due to mobile nature of Na_2O and K_2O, their use in classification of older lavas is not reliable. The other diagrams based on less or immobile elements, have been used to classify the magma types of these volcanics.

Miyashiro and Shido (1975) have proposed a series of plots in which the various major and trace elements are plotted against FeO*/MgO ratio to distinguish tholeiites from calc-alkaline basalts.

Following the same methods the SiO_2, FeO* and TiO_2 contents of Ongarbira volcanics are plotted against FeO*/MgO ratios. In SiO_2-FeO*/MgO plot (Fig. 8) the Ongarbira volcanics show a scatter but most of the plots occupy the field of tholeiite. However, in FeO*-FeO*/MgO variation diagram (Fig. 9) these volcanics follow the abyssal tholeiite trend as identified by Miyashiro and Shido (1975). In TiO_2-FeO*/MgO diagram (Fig. 10) these volcanic rocks appear as tholeiites with oceanic or abyssal tholeiite affinity as they occupy the enclosed field. In Ni-FeO*/MgO variation diagram (Fig. 11) when the values of Ongarbira volcanics are plotted they fall in abyssal tholeiite

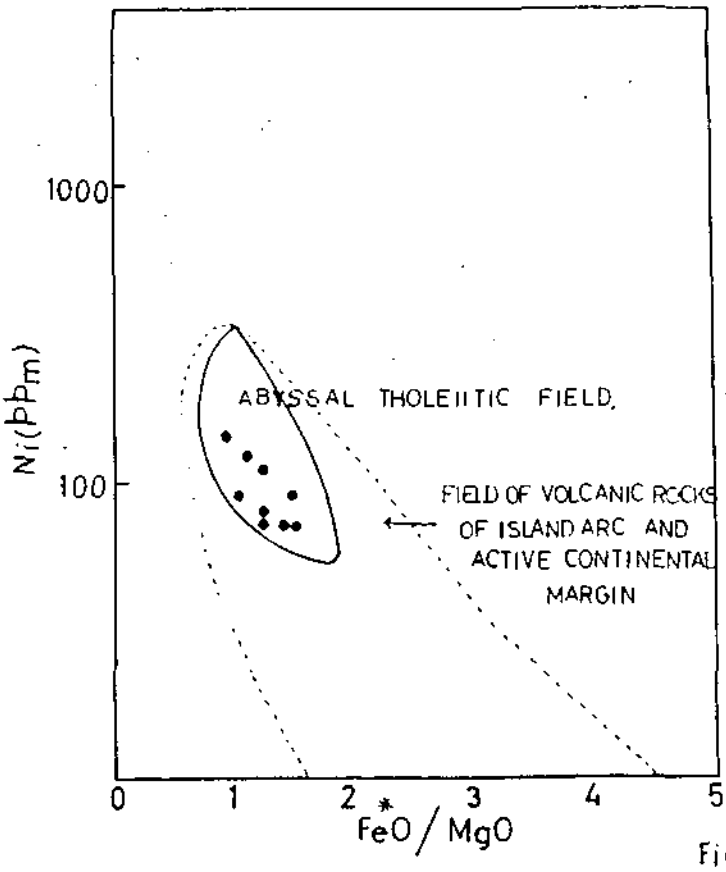


Fig.11.

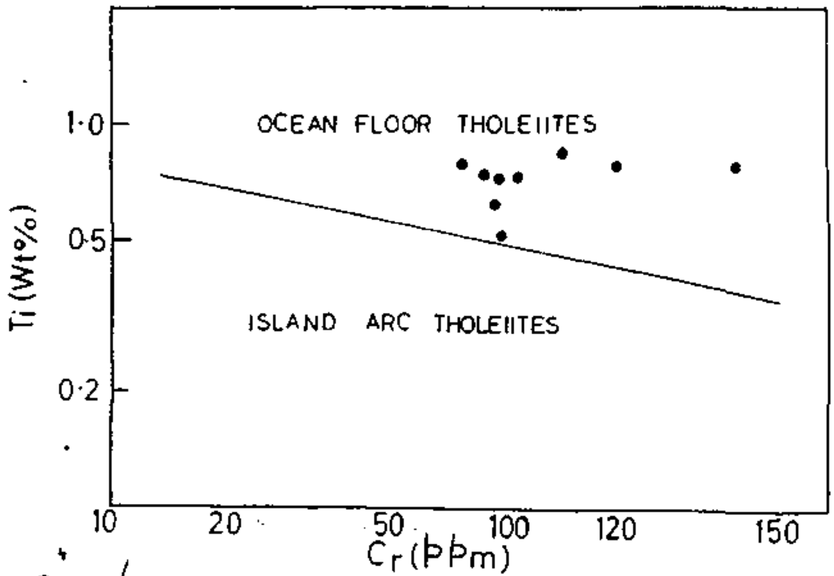
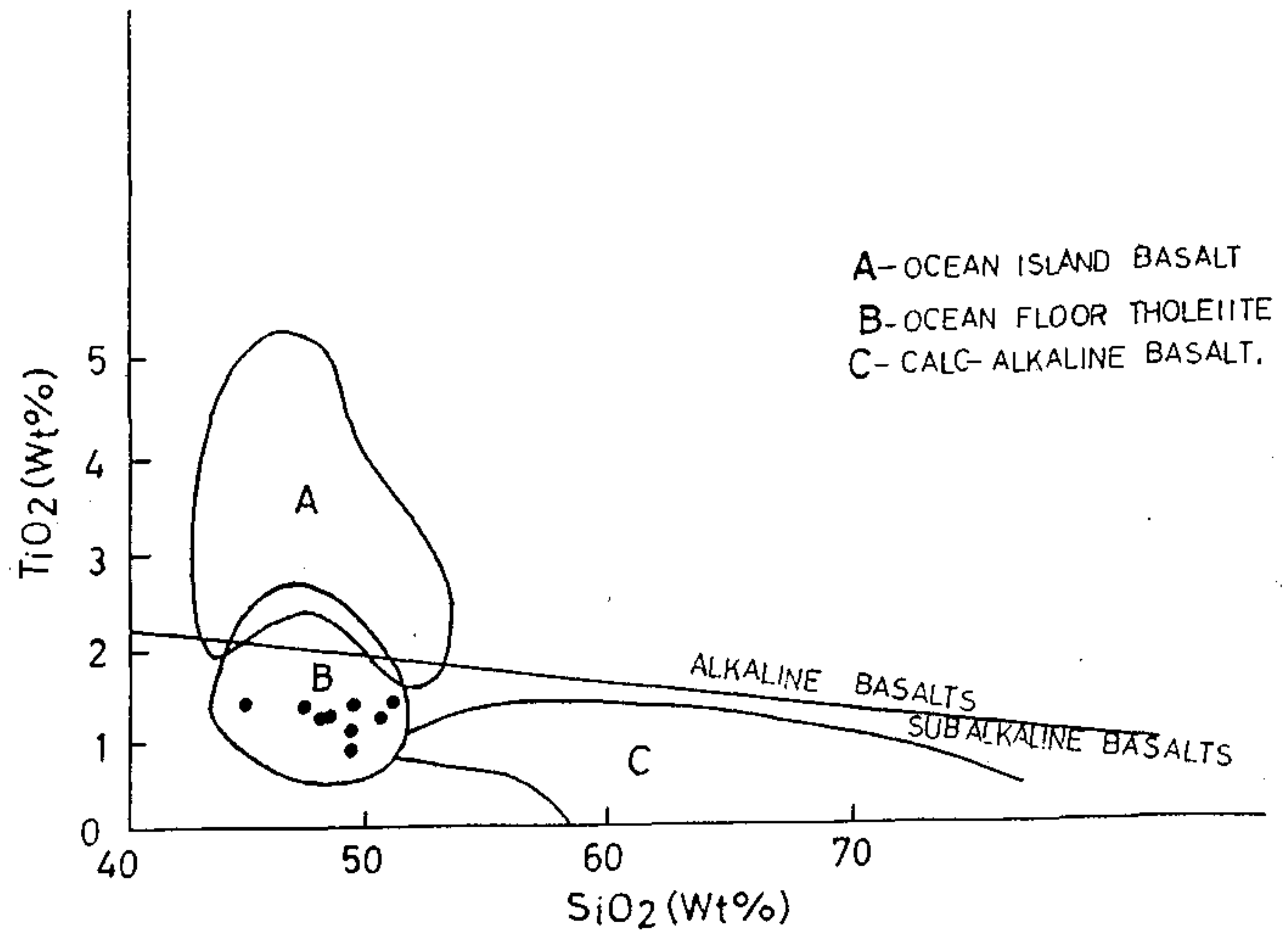


Fig.12.

FeO / MgO — Ni, Cr—Ti, PLOT FOR ONGARBIRA VOLCANICS.



SiO_2– TiO_2 PLOT FOR ONGARBIRA VOLCANICS.

Fig.13.

field. The SiO_2 versus TiO_2 plot (McDonald and Katasura, 1964; Whitehead and Goodfellow, 1978) is also very helpful in distinguishing the composition as well as eruptive environment of basic volcanics. It is evident from the plot (Fig. 13) that Ongarbira volcanics fall below the discrimination line indicating their tholeiitic nature and occupy the field of ocean floor tholeiite. The Ti-Cr plot (Pearce, 1976) is also useful to distinguish the eruptive environment. When the Ongarbira volcanics are plotted in such a manner (Fig. 12) they again occupy the field of ocean floor tholeiite.

On the bases of above discussed various diagrams the Ongarbira volcanics can be considered as tholeiitic rocks having a close affinity with oceanic tholeiites. However, the high MgO content (8.20 per cent to 11.70 per cent with average 9.59 per cent) and high CaO/Al_2O_3 ratio (average 1.09) of these rocks closely resemble with those reported for komatiitic rocks

The possibility of basaltic komatiite in the Archean of Singhbhum district has also been suggested by Viswanathan and Sankaranan (1973). So it is important to discuss this aspect in the light of various criteria which have been proposed to distinguish the komatiitic rocks.

BASALTIC KOMATIITIC AFFINITY :

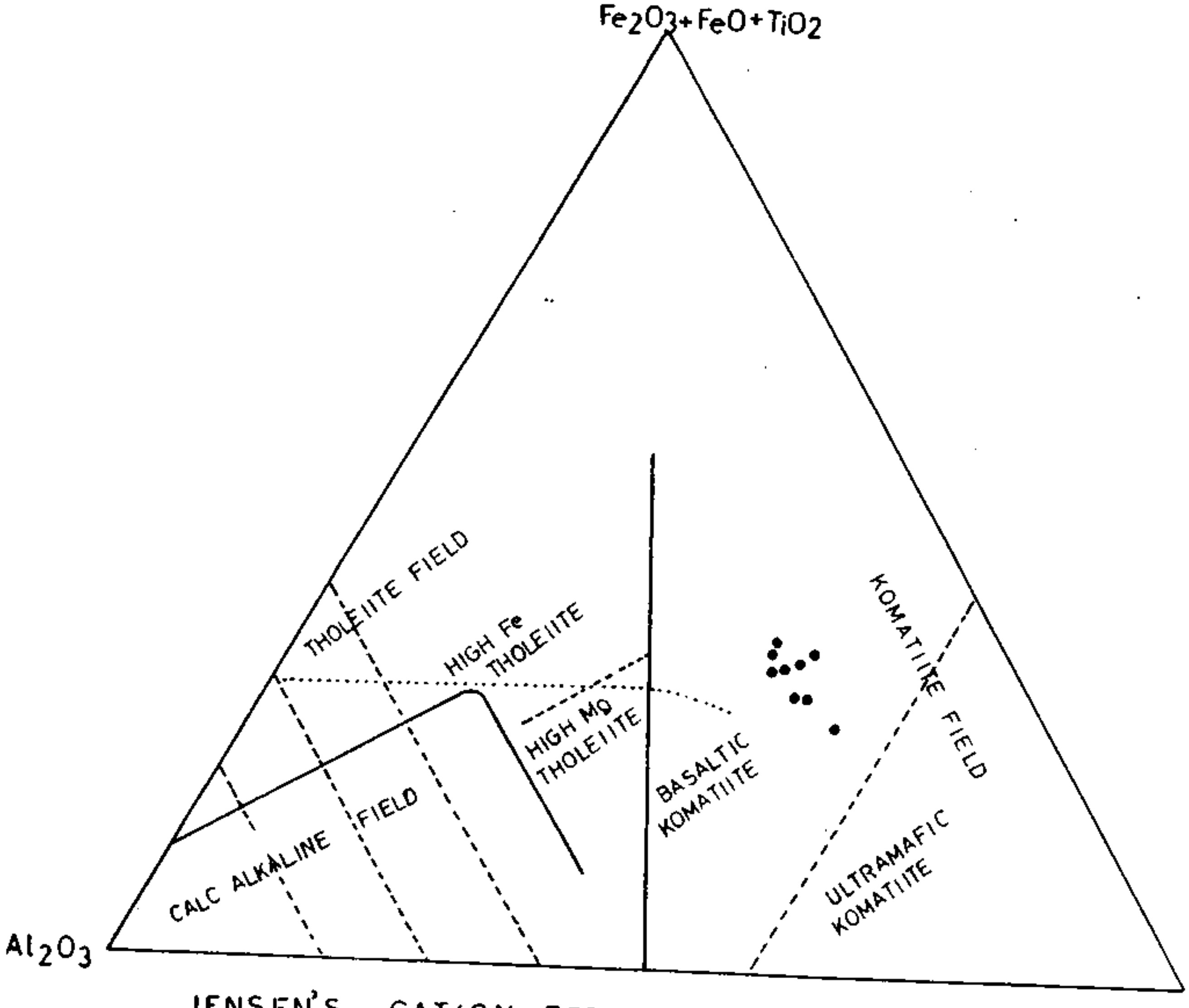
The komatiites were first reported by Viljoen and Viljoen (1969a) in South Africa. Komatiites are characterised by containing high MgO, higher CaO/Al_2O_3 ratio and very low alkalies and TiO_2 contents (Brooks and Hart, 1974; Arndt and Nisbet, 1982). The spinifex or quench texture is considered as an important feature of komatiites (Arndt and Nisbet, 1982).

However, because of their Archean age, most of the komatiitic rocks are altered in nature in which the original texture have generally been obliterated. On the bases of chemical composition, structural and textural evidences, natural geochemical discontinuities, the komatiites have generally been classified into Peridotite Komatiite (PK) and Basaltic Komatiite (BK). The peridotite komatiite is an ultramafic rock which is characterised by the presence of more than 18 per cent MgO content (Arndt and Nisbet, 1982). On the other hand, mafic rocks having less than 18 per cent MgO have been classified as basaltic komatiites. The characteristic features of basaltic komatiites suggested by Brooks and Hart (1974) and Arndt and Nisbet (1982) are as follows.

SiO_2, 46 per cent to 53 per cent; CaO/Al_2O_3 ratio 0.8; TiO_2, K_2O 0.9 per cent and MgO 9 per cent.

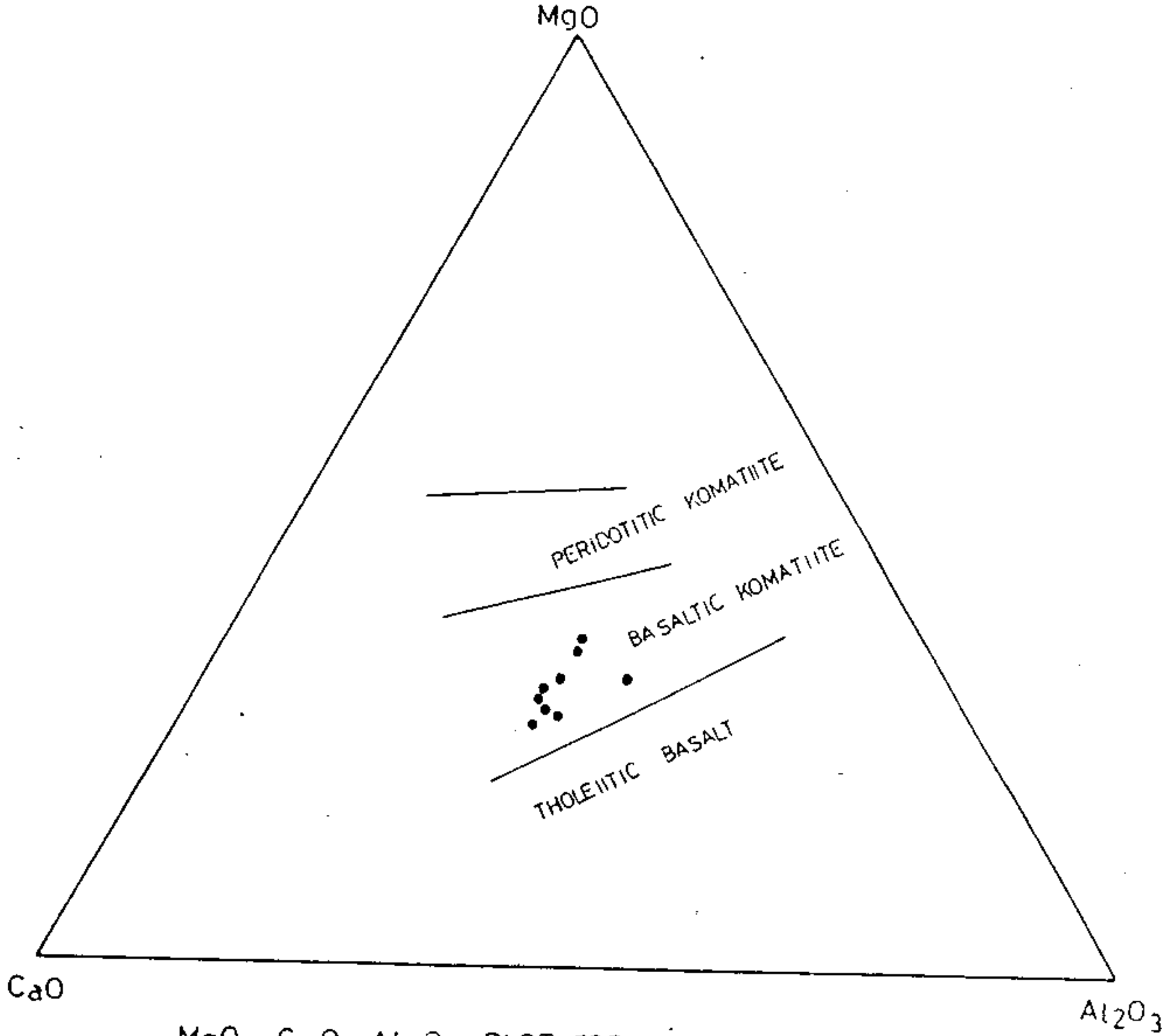
All analysed samples of Ongarbira volcanics (Table-I) have MgO content more than 8 per cent (range 8.2 per cent to 11.70 per cent, average 9.59 per cent, which coincides to the value of basaltic komatiite, proposed by Arndt and Nisbet (1982).

All analysed samples of Ongarbira volcanics have CaO/Al_2O_3 ratio more than 0.8 (range 0.8 to 1.28, average 1.09) which is



JENSEN'S CATION TERNARY PLOT FOR ONGARBIRA VOLCANICS.

Fig.14.



$MgO - CaO - Al_2O_3$ PLOT FOR ONGARBIRA VOLCANICS.

Fig.15

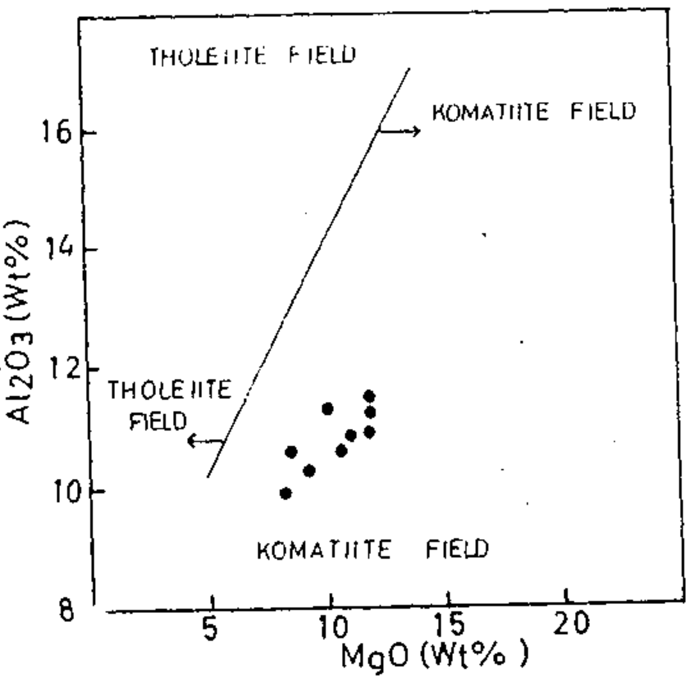


Fig.16.

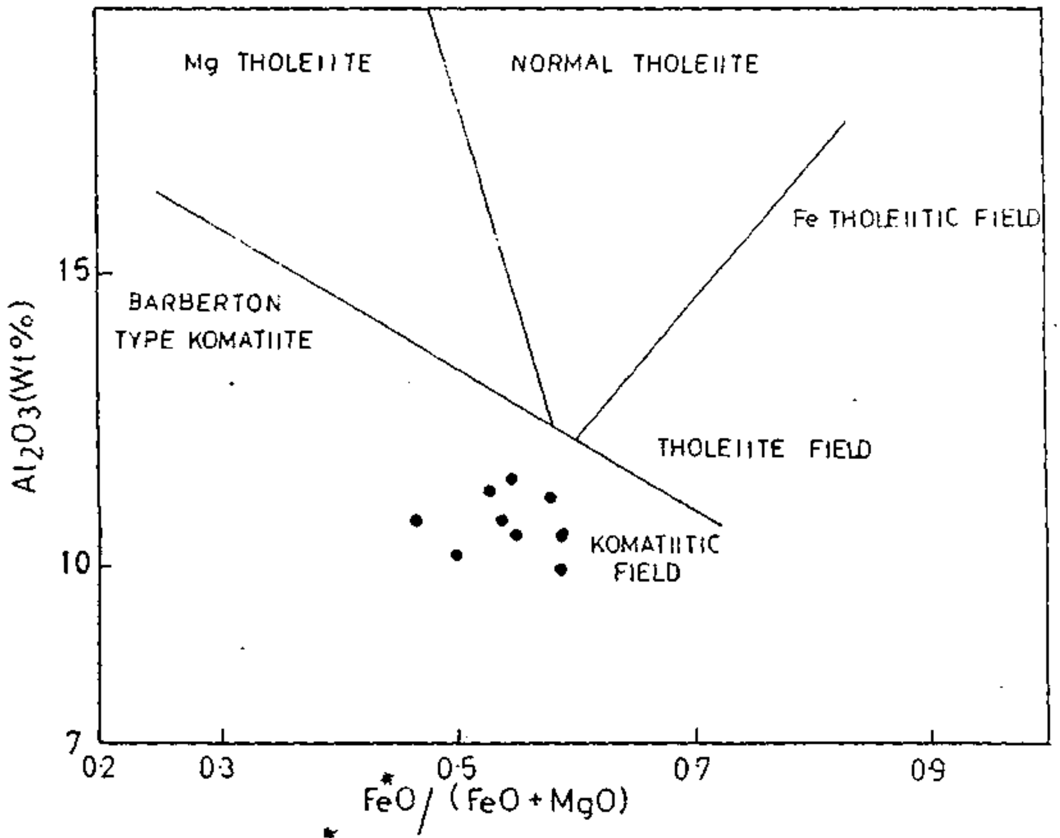


Fig.17.

MgO – Al_2O_3, FeO^*/(FeO+MgO) – Al_2O_3, PLOTS FOR ONGARBIRA VOLCANICS an important criterion for basaltic komatiite (Brooks and Hart, 1974; Arndt and Nesbitt, 1982). The MgO and CaO/Al_2O_3 ratio based criteria classify the Ongarbira volcanics as basaltic komatiites. For further confirmation their data are plotted in various discrimination diagrams which have been proposed by many workers to distinguish peridotite komatiite, basaltic komatiite and tholeiite.

Al_2O_3 - ($FeO + Fe_2O_3 + TiO_2$) - MgO (all in cation per cent) ternary diagram was porposed by Jensen (1976) and has been widely used to distinguish chemically the basaltic komatiites and calc-alkaline suites. Various constituents of Ongarbira volcanics are plotted in this diagram in figure-14. It is evident from the figure that all the samples of Ongarbira volcanics fall in the field of basaltic komatiites.

Viljoen and Viljoen (1969b) have proposed $CaO-Al_2O_3-MgO$ triangular diagram to classify Onverwacht volcanics into komatiites and tholeiites. The data of Ongarbira volcanics plotted in this ternary diagram (Fig. 15) again indicate a basaltic komatiitic affinity for these rocks. Al_2O_3 versus MgO diagram, proposed by Viljoen et al. (1969b) is also very useful to distinguish komatiites from tholeiites. In this diagram the weight percentages of oxides are used. The Ongarbira volcanics again show their basaltic komatiitic nature when plotted in Al_2O_3 versus MgO diagram (Fig. 16).

The Al_2O_3 versus $FeO^*/(FeO + MgO)$ diagram was suggested by Arndt et al (1977). The constituents of Ongarbira volcanics when plotted in this diagram (Fig. 17) to discriminate the komatiites and tholeiites, occupy the field of komatiites. Therefore, it may be concluded that these volcanics have a great affinity with komatiites and may be classified as basaltic komatiites on the basis of their geochemical characteristics.

GEOCHEMICAL COMPARISON WITH OTHER ROCKS OF BASALTIC COMPOSITION :

The composition of Ongarbira volcanics are compared with those of tholeiites of different tectonic environments and basaltic komatiites of various localities of the world in Tables-VI and VII. The following different localities have been selected for comparative study.

Tholeiites :

1- Average tholeiites, Dalma metavolcanics, India (Banerjee, 1982).
2- Average tholeiites, Dhanjor lavas, India (Ibid).
3- Average Depleted Archean tholeiites (Condie, 1976).
4- Average Enriched Archean tholeiites Ibid .
5- Average Mid-Oceanic ridge basalts Ibid
6- Average Island arc tholeiites Ibid

7- Average Calc-alkaline tholeiites Ibid.

8- Average Continental rift tholeiites Ibid.

Basaltic Komatiites :

1- Average basaltic komatiites, Debari volcanics, Udaipur, India (Raza and Khan, 1987).

2- Average basaltic komatiites, Kolar schist belt, India (Rajamani et al., 1985).

3- Average basaltic komatiites, Betscove, Newfoundland (Upadhyay, 1982).

4- Average basaltic komatiites, Destor Quebec (Ludden and Gelinas, 1982).

5- Average basaltic komatiites, Munro Township basalt Cycle I and III (Arndt and Nesbitt, 1982).

6- Average basaltic komatiites, Minnesota, U.S.A. (Schulz, 1982).

Average SiO_2 content of Ongarbira volcanics (48.95) is nearly similar to Enriched Archean tholeiites (average 49.5), Mid-Oceanic ridge basalts (average 49.8), and higher and Dalma tholeiites (average 46.03) while the rest tholeiites of given localities have higher SiO_2 contents. When SiO_2 content of Ongarbira volcanics is compared with those of basaltic komatiites of various localities, it appears to be nearly similar to Debari basaltic komatiites (average 49.15) and

Munro Township basaltic komatiite except basaltic komatiite of Kolar schist belt (Avg. 45.39) of higher values.

Al_2O_3 content of Ongarbira volcanics (avg. 10.75) is lower than all given tholeiites and basaltic komatiites of Tables-VI and VII except basaltic komatiites of Minnesota (avg. 9.29).

The average FeO* content (11.61) of Ongarbira volcanics is well within comparable range of Enriched Archean tholeiites (avg. 11.69), Dalma tholeiites (avg. 12.2), Continental rift tholeiites. While other tholeiites have lesser values except Dhanjori tholeiites (avg. 1304) which is of higher value. When FeO* content of Ongarbira volcanics (avg. 11.61) is compared with basaltic komatiites it appears nearly similar to Debari basaltic komatiites (avg. 12.2), higher than basaltic komatiites of Betscove (avg. 7), basaltic komatiite of Destor Quebec (avg. 9.13) while other localities possess higher values. CaO content (avg. 11.54) is fairly similar to Depleted Archean tholeiites (avg. 11.6), Mid-Oceanic ridge basalts (avg. 11.2) and higher than those of other tholeiites as well as basaltic komatiites of various localities except Minnesota basaltic komatiites (avg. 12.46).

MgO content (avg. 9.59) of Ongarbira volcanics is higher than all tholeiites given in Table-VI except Dalma tholeiites (avg. 12.77) and lower than all basaltic komatiites of various localities. The average TiO_2 content of Ongarbira volcanics, when compared with tholeiites and basaltic komatiites, it appears to be similar to Enriched Archean tholeiites (avg. 1.2), Debari basaltic komatiites (avg. 1.21) basaltic komatiites of Kolar schist belt (avg. 1.05) basaltic komatiites, Munro Township basalts Cycle I (avg. 1.08) basaltic komatiites of Minnesota (avg. 1.08) and higher than other tholeiites except Continental rift tholeiites (avg. 2.2).

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CHAPTER-V

TRACE ELEMENT GEOCHEMISTRY

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GENERAL STATEMENT :

Trace elements in comparison to major elements have least concentration in the crust and mantle but their applications in understanding the evolutionary history of basaltic magmas are very wide and useful (Taylor, 1965; Gast, 1968; Haskin et al., 1974). The concentration of trace elements in Archean volcanic rocks have been used to infer the genesis of magmas, environment of eruptions, and physico-chemical conditions at that time. Concentration of trace elements is particularly controlled by the following three factors (Gast, 1968).

(i) The concentration of that element in source of liquid.

(ii) The extent of chemical fractionation that takes place during melting.

(iii) The crystallization of liquid.

Trace elements are also sensitive indicators of both, degree and mechanism of differentiation into either liquid or crystalline phase because of their strong partitioning character and this character provides a better tool to prepare a model of igneous fractionation (Taylor, 1965; Gast, 1968; Haskin et al., 1970; Hubbard et al., 1971 and Weill et al., 1974).

TRACE ELEMENT DISTRIBUTION AND COMPARISON :

In the present study nine samples of Ongarbira volcanics are analysed for Ni, Cr, Co, Rb, Sr, Ba, Cu, Li, Zn. Data are presented in Table-IV and distribution of various trace elements is discussed as follows.

Ni is considered to be very sensitive element to fractional crystallisation in the early stage of magmatic differentiation. Its concentration in basaltic rocks is generally controlled by ferromagnesian minerals like olivine and also partially by pyroxenes, in which Ni generally replaces magnesium diadochically in the mineral structures. The concentration of Ni in Ongarbira volcanics ranges from 72 ppm to 105 ppm with an average of 88 ppm. When compared with other basaltic komatiites of the world and tholeiites of different tectonic environments (Tables-VI and VII), the Ni content of these rocks (avg. 88 ppm) appears to be appreciably lower than the basaltic komatiites of Kolar schist belt (avg. 671 ppm, Rajamani et al., 1985), Bets Cove (avg. 298 ppm, Upadhyay, 1982) and Dalma metavolcanics (avg. 405 ppm, Banerjee, 1982) but closely similar to Mid-oceanic ridge basalts (avg. 100 ppm, Condie, 1976). Ni generally enters into olivine in the early stage of magmatic differentiation (Vogt, 1923; Wager and Mitchell, 1951; Ringwood, 1955; Storm and Holland, 1957; Turekian, 1963). Owing to the tendency of enrichment in the early products of differentiation, the parallel increase of Ni with MgO is expected. To see the coherence of Ni with MgO, their contents in Ongarbira volcanics have been plotted in Ni-MgO variation diagram in which it is evident that Ni have a positive correlation with MgO (Fig. 18).

Cr which is also a sensitive element to fractional crystallisation, varies from 80 to 140 ppm with an average of 117 ppm in these rocks. The Ongarbira volcanics appear Cr depleted showing appreciably low values (avg. 117 ppm) when compared with the basaltic komatiites of Kolar schist belt (avg. 1886 ppm, Rajamani et al., 1985), basaltic komatiites of Minnesota (avg. 926 ppm, Schulz, 1982), basaltic komatiites of Betscove (avg. 858 ppm, Upadhyay, 1982), Dhanjori lavas (avg. 490 ppm, Banerjee, 1982) and Depleted Archean tholeiites (avg. 490 ppm, Condie, 1976). However, the Cr content of Ongarbira volcanics closely matches with Continental rift tholeiites (avg. 100 ppm, Condie, 1976).

The Cr alongwith Ni preferentially enters into octahedral co-ordination sites of ferromagnesian minerals. Wager and Mitchell (1953), McDougall and Lovering (1963) and Turekian (1963) have observed the coherence of Cr in the early formed pyroxenes. It is also observed that Cr has got a close affinity

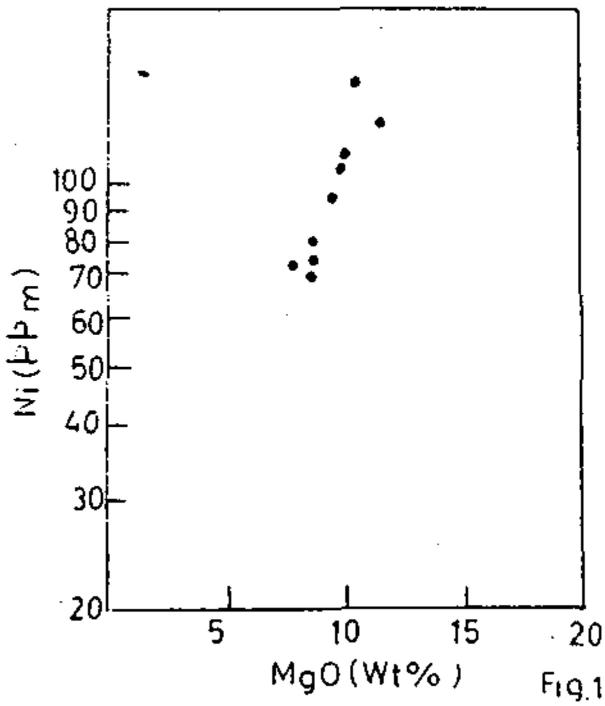

Fig.18.

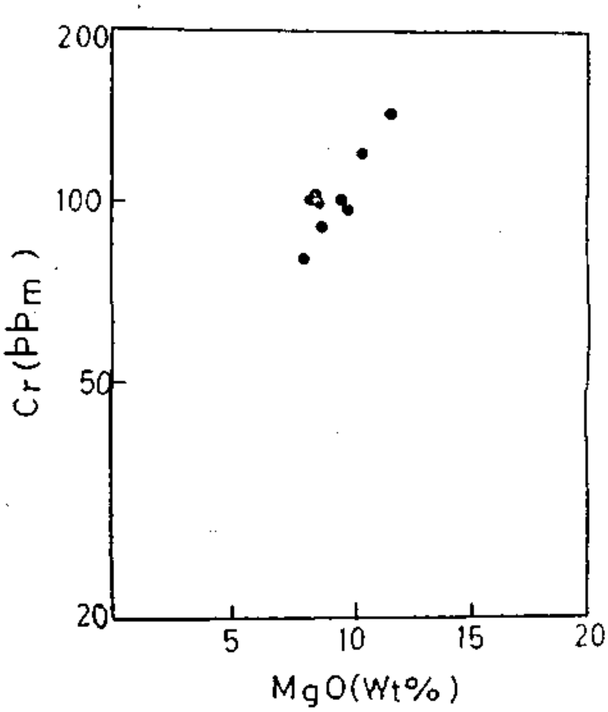

Fig.19.

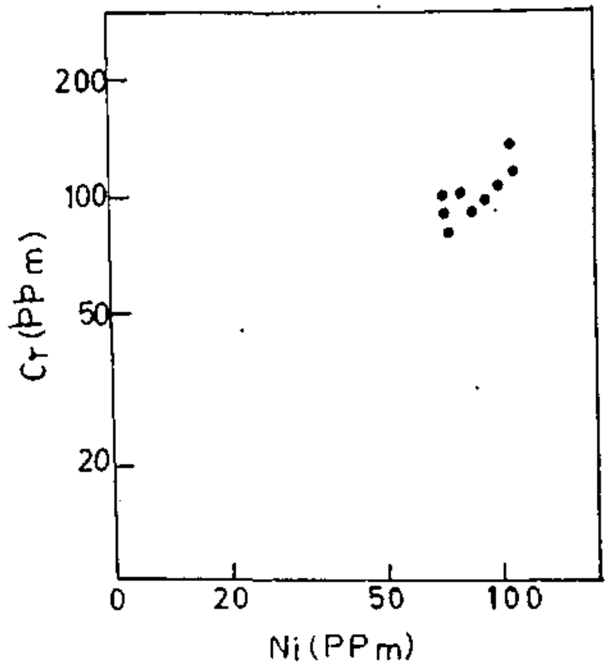

Fig- 20.

MgO–Ni, MgO–Cr, Ni–Cr, PLOTS FOR
ONGARBIRA VOLCANICS.

for olivine structures but because of valency difference it gets incorporated in a limited amounts. Nesbitt and Sun (1976) and Jahn et al (1980) have observed that the Cr concentration in the rocks possessing MgO $>$ 15 per cent decreases drastically as MgO concentration decreases while in the rocks possessing $<$ MgO 15 per cent the Cr content remains constant or increases slightly with increasing MgO content. In figure-19, the Cr concentration of Ongarbira volcanics are plotted against their MgO contents in order to examine their genetic signficance. A positive correlation of Cr with MgO is evident from this plot. The plots Cr-MgO and Ni-MgO of Ongarbira volcanics (Figs. 17, 18) showing identical curves, suggest coherence of Cr and Ni with MgO and advocate for their comparability in olivine and pyroxene. For these rocks, the Ni-Cr plot (Fig. 20) also shows a positive correlation with a curve very identical to those of Ni-MgO and Cr-MgO plots. This leads to interpret that during the differentiation the Ni and Cr partitioned into olivine and pyroxene with more or less same amounts. The positive relationship between Ni-MgO and Cr-MgO in komatiitic rocks have also observed by many workers, (Nesbitt and Sun, 1976; Hawksworth and Onions, 1977; Jahn et al., 1979; Auvray et al., 1982; Barley and Bickle, 1982; Binns et al., 1982; Beswick, 1982).

In komatiitic rocks these relationships have been described in terms of progressive melting of an ultramafic source by Nesbitt and Sun (1976). However, on the basis of distribution coefficient of Ni in different minerals Jahn et al (1976) have suggested that fractional crystallization trend more nearly coincides with these trends than partial melting trends.

The Co contents of Ongarbira volcanics show a range from 12 ppm to 19 ppm with an average Co content of these rocks (avg. 16 ppm) when compared with those of basaltic komatiite of Kolar schist belt (avg. 64 ppm, Rajamani et al., 1985), Dalma metavolcanics (avg. 102 ppm, Banerjee, 1982), appears depleted, like their Ni and Cr contents. However, it compares well with that of Island arc tholeiites (avg. 20 ppm, Condie, 1976). It has been observed that Co enters into the same minerals as Ni but comparatively in lesser amounts and with more constant values (Wager and Mitchell, 1951; Cornwall and Rose, 1957; Wilkinson, 1959; Carr and Turekian, 1961; Burns and Fyfe, 1964). Generally in basaltic rocks Co like Ni and Cr also preferentially occupies the octahedral co-ordination sites (Burns and Fyfe, 1964). The concentration of Co is generally controlled by crystallisation of olivine in magmatic evolution. However, a linear relation between Co and MgO may be expected (Sandel and Goldich, 1943). The Co-MgO plot (Fig. 21) of Ongarbira volcanics indicates a sympathetic positive relationship, therefore, justifying its coherence with MgO.

The depleted values of Ni, Cr and Co lead to interpret the fractionation of olivine and partially of pyroxene before the emplacement of Ongarbira volcanics.

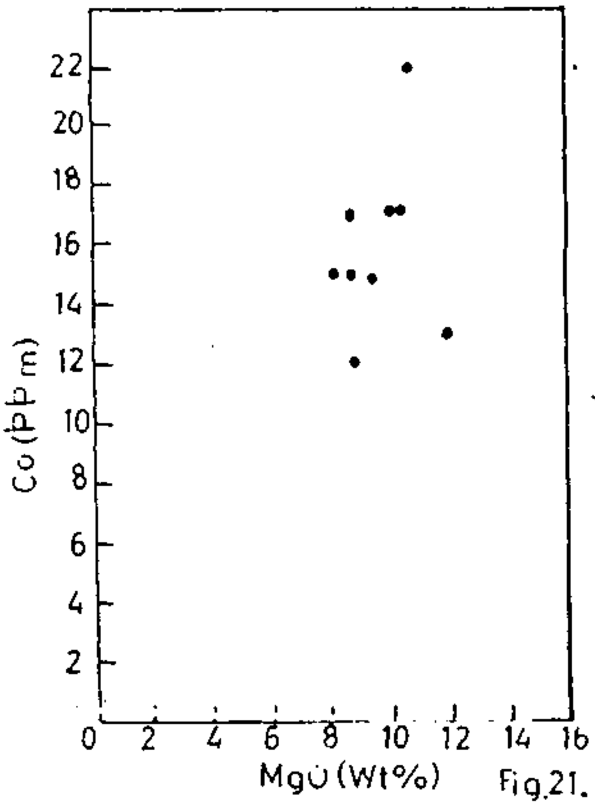

Fig.21.

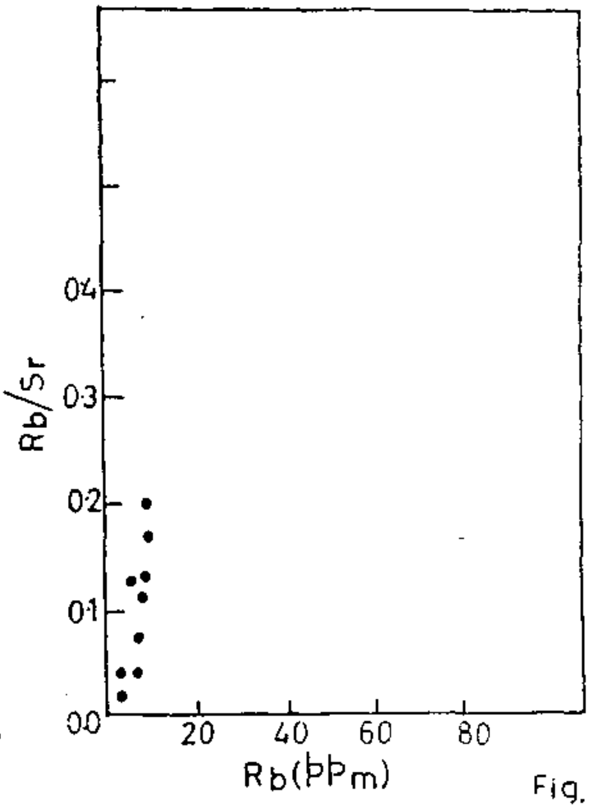

Fig.22.

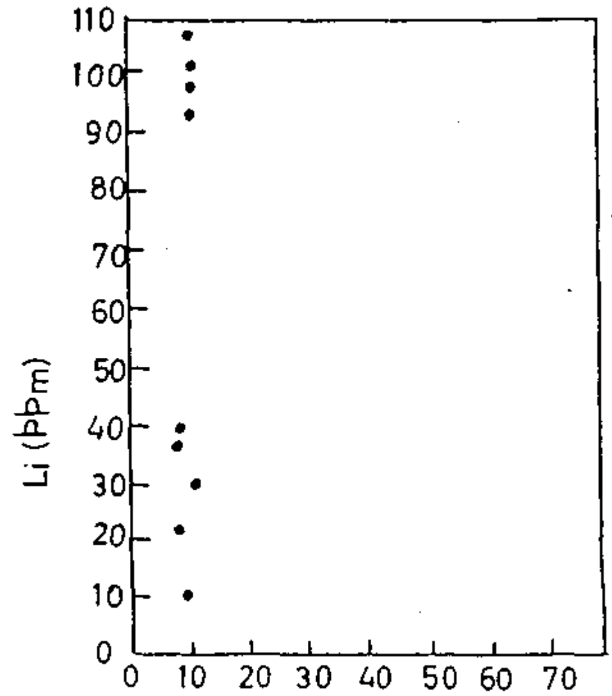

Fig. 23.

MgO – Co, Rb-Rb/Sr, MgO – Li, PLOTS FOR ONGARBIRA VOLCANICS.

The principal carriers of rubidium are potassium feldspars and micas while in other feldspar and feldspathoid of basic rocks, Rb appears to be present in detactable amount (Prinz, 1967). The Rb content in latest pyroxene, analcite and orthoclase, has also been observed (Wager and Mitchell, 1951; Wilkinson, 1959). Rb concentration in Ongarbira volcanics ranges from 2 to 9 ppm with an average of 7 ppm showing a close similarity with those of basaltic komatiite of Debari (avg. 7 ppm, Raza and Khan, 1987), basaltic komatiite of Kolar schist belt (avg. 7 ppm, Rajamani et al., 1985), but when it is compared with Dalma tholeiite (avg. 20 ppm, Banerjee, 1982) it appears to be considerably lower. When Rb contents of Ongarbira volcanics are plotted against the Rb/Sr ratio (Fig. 22) a positive correlation appears.

Sr is generally incorporated in the structure of Ca rich minerals like pyroxene, plagioclase, apatite and as feldspars and feldspathoids (Nockolds and Allen, 1953; Butler and Skiba, 1962; Heir, 1962). On the basis of ionic radii Sr can replace Ca^{+2} cations in Ca-rich minerals and K-feldspar capture Sr^{+2} ion in place of K^{+} ions. The Sr content of Ongarbira volcanics ranges between 45 ppm and 167 ppm with an average of 79 ppm. This value is closely similar to those of Munro Township basaltic flows of Cycle-III (avg. 83 ppm, Arndt et al., 1982), Dhanjori tholeiite (avg. 83 ppm, Banerjee, 1982) but appears to be lower than those found in basaltic komatiites belt of Kolar schist belt (avg. 120 ppm, Rajamani et al., 1985), Debari basaltic komatiites (avg. 174 ppm, Raza and Khan, 1987), Calc-alkaline tholeiites (avg. 300 ppm, Condie, 1976) and Continental rift tholeiites (avg. 350 ppm, Condie, 1976).

Ba is found mainly in feldspar, feldspathoid and to a small extent in apatite. Cornwall and Rose (1957) have found a significant amount in clinopyroxene and chlorite also. The concentration of Ba and Sr depend upon the temperature of crystallization (Noll, 1934; and Engelhardt, 1936). High temperature K-feldspars may possess high concentration of Ba and Sr than low temperature K-feldspars.

Ba content in Ongarbira volcanics ranges between 114 and 196 ppm with an average of 157 ppm. They show high values of Ba contents (avg. 157 ppm)when compared with Debari basaltic komatiite (avg. 70 ppm, Raza and Khan, 1987), basaltic komatiite of Kolar schist belt (avg. 51 ppm, Rajamani et al., 1985), basaltic komatiite of Munro Township basalt cycle-III (avg. 98 ppm, Arndt et al., 1982), Dalma tholeiites (avg. 28 ppm, Banerjee, 1982) and Mid-oceanic ridge basalt (avg. 11 ppm, Condie, 1976) but it appears to be similar to that found in Dhanjori lava (avg. 150 ppm, Banerjee, 1982). Ba and Sr behave similar to Ca and a positive correlation may be expected. However, Ongarbira volcanics do not show such relationships between Ba, Sr and Ca.

Cu content of Ongarbira volcanics ranges from 47 ppm to 182 ppm with an average of 118 ppm. Cu because of its strong affinity for sulphur during magmatic differentiation, occurs as sulphides in basaltic rocks (Rankama and Sahama, 1950). It has been suggested by Wager and Mitchell (1951) that during early stage of crystallisation of basaltic magma, Cu in the absence of sulphur occurs free in the magma and becomes incorporated with silicate minerals. Cu generally gets enriched in plagioclase or iron rich differentiates (Prinz, 1967). However, it is generally believed that Cu content increases in some non-sulphide minerals with advancing fractionation (Wager and Mitchell, 1951, 1957; Cornwall and Rose, 1957; Tiller, 1959; McDougall and Lovering, 1963). Cu contents of Ongarbira volcanics (avg. 118 ppm) when compared with Debari basaltic komatiite (avg. 152 ppm, Raza and Khan, 1987) and Dalma tholeiite (avg. 121 ppm, Banerjee, 1982) appears almost similar.

Lithium generally enriched into micas, amphiboles and pyroxenes, during the course of crystallisation (Rankama and Sahama, 1950). It does not go into plagioclase and K-feldspar during the main stage of crystallisation though it often forms independent minerals in pegmatites. Li contents of Ongarbira volcanics show a wide range of variation (20 to 210 ppm, avg. 82 ppm). The average Li content of these rocks (avg. 82 ppm) appears lower than Debari basaltic komatiite (avg. 144 ppm, Raza and Khan, 1987). Hortsman (1957) agreed with Strock (1936) that distribution of Li is probably controlled by Fe-Mg sites. However, Heir (1962) considered that a limited amount of Li substitution for Na is possible in plagioclase and Na rich alkali feldspar. When Li contents of Ongarbira volcanics are plotted against their MgO content a positive correlation is observed (Fig. 23).

Zn content of Ongarbira volcanics varies from 52 ppm to 136 ppm with an average of 80 ppm. Zn enriches into the structure of magnetite and ilmenite because during magmatic differentiation, it remains largely in the residual melt throughout the early stage of crystallisation (Rankama and Sahama, 1950). It replaces Fe^{+2} and Mg^{+2} diadochically in the mineral structure. The average Zn content of Ongarbira basaltic komatiite (avg. 80 ppm) appears low when compared with Debari basaltic komatiite (avg. 123 ppm, Raza and Khan, 1987). However when compared to that of Depleted Archean tholeiite, Island arc tholeiite, calc-alkaline tholeiite (avg. 80 ppm, Condie, 1976) it appears closely similar.

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CHAPTER-VI

PETROGENESIS

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In this chapter an attempt is made to distinguish the processes responsible for the evolution of basic volcanics of Ongarbira area. The experimental studies have shown that the chemical composition of magma depends upon the depth, water contents and physico-chemical conditions at the source region in mantle (Walker and Poldervaart, 1949; Osborn, 1959, 1962; Yoder and Tilley, 1962; Green and Ringwood, 1964; Kuno, 1966; Yoder, 1969; Kushiro, 1970; Kushiro et al., 1972; Green, 1976). It is generally agreed that the partial melting of upper mantle produces the basaltic magma (Green and Poldervaart, 1958; Hurley et al., 1962; Yoder and Tilley, 1962; Green and Ringwood, 1967; Manson, 1967; Green, 1976; O'Hara, 1977; Miyashiro, 1978). However, the genetic processes for different suites are still a topic of considerable debate. The chemical characteristics of Ongarbira volcanics as discussed in preceeding chapters, suggest that they are basaltic komatiite in nature. The concentration of some major and trace elements, their geochemical behaviours and elemental relationships can be used to infer the evolution of these basaltic komatiites.

The basaltic komatiites may be generated at depths greater than 100 km by lower extent of melting than that for peridotite komatiite (Hynes and Francis, 1981) or they may have been derived by differentiation processes (Francis and Hynes, 1979). The elements like Mg, Ni and Cr play important role in petrogenetic studies and show certain significant relationships in the case of Ongarbira volcanics. In Ni-MgO, Cr-MgO and Ni-Cr variation diagrams (Figs. 18, 19, 20), the Ongarbira volcanics show a continuumof composition. The positive relationship between Ni-MgO, Cr-MgO and Ni-Cr suggest that not only olivine but also some pyroxenes have been fractionated from the melt before its emplacement. The fractionation of olivine and partially of pyroxene has also been substantiated by the fact that Ongarbira volcanics possess considerably depleted values of Ni, Cr and Co. Thus with the help of above discussion, it may be suggested that the parent magma of Ongarbira volcanics was rich in olivine in the early stage. Probably after partial melting of mantle, the magma started rising from the zone of magma generation to shallow reservoir. During ascend the magma cooled up to the temperature where olivine crystallised and settled down. The crystallisation of olivine might have been immediately followed by pyroxene which along with the olivine fractionated from the melt. So the magma reaching to the surface was appreciably differentiated.

Hanson and Langmuir (1978) have proposed MgO-FeO diagram to obtain many petrogenetic informations for mafic and ultra-

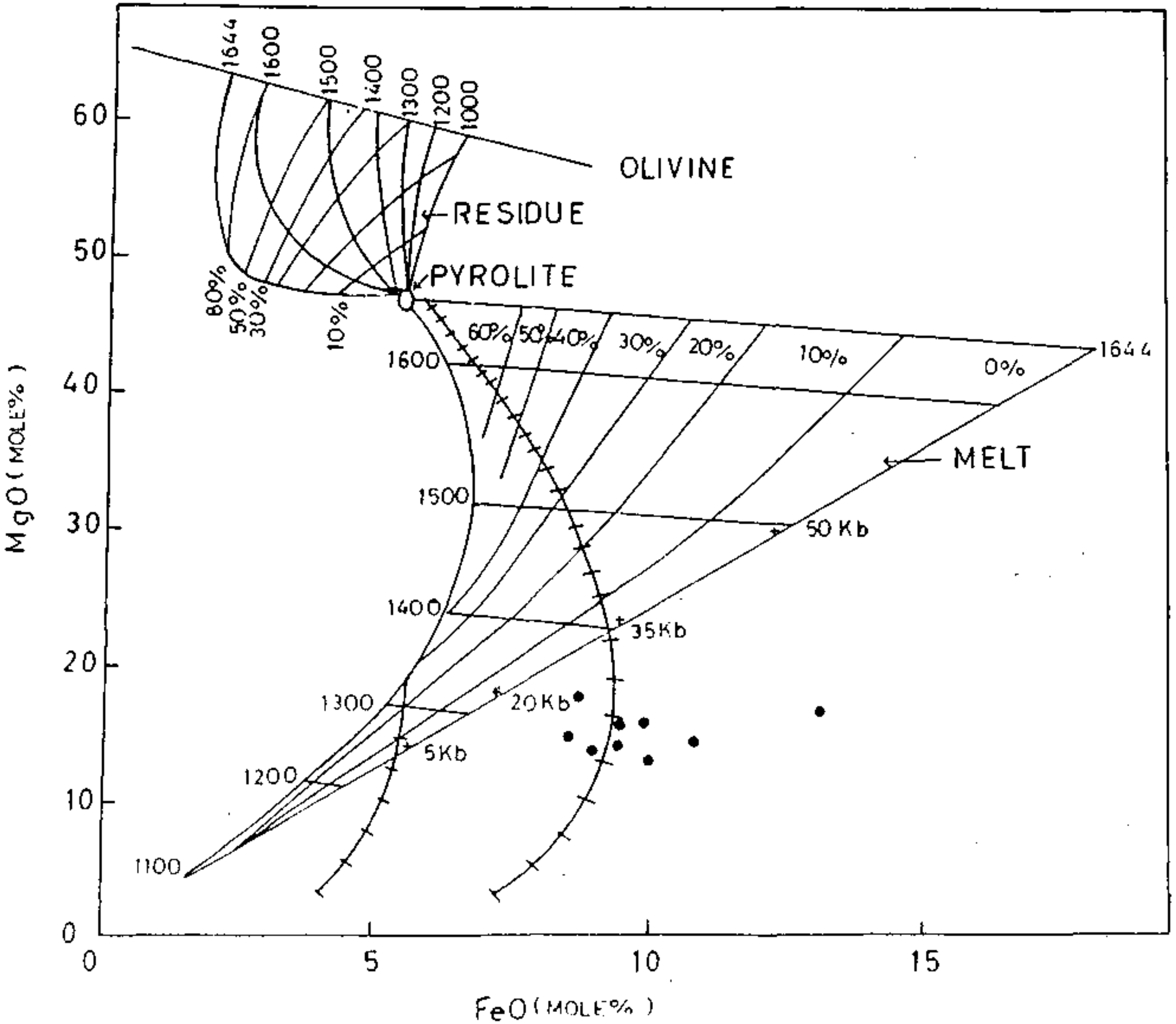

Fig. 24.

FeO - MgO, PLOT FOR ONGARBIRA VOLCANICS.

mafic rocks. They assumed a pyrolite mantle and batch melting as a most probable mode of melting. In this diagram the composition of olivine in equilibrium melts, the composition of pyrolite, and compositional field of melt and residue during partial melting of a pyrolite mantle are shown in terms of FeO* and MgO contents. Here the melt and residue fields are contoured for temperature and extent of melting of pyrolite. The line above the residual field gives the olivine composition. The olivine fractionation line for various melts generated at different temperatures due to extent of melting has been shown by two curves with tics. In this diagram the rocks which plot to the right and below the per cent melt line, represent the differentiated melts while undifferentiated to less differentiated melts are represented to the left of per cent melt line. The temperature and extent of melting (pyrolite mantle) involved in their genesis, can be interpreted by the position of this plot in the melt field. The FeO* and MgO contents, in mole per cent of Ongarbira volcanics are plotted in the diagram of Hanson and Langmuir (1978) (Fig. 24). It is observed that all the samples of these volcanics plot well below the melt field. This feature indicates that before the emplacement, the magma for these rocks have undergone differentiation by fractional crystallisation. Therefore, supports the conclusion that the parental melts of these rocks have suffered fractionation of, at least olivine and pyroxene.

The more informative discussion and interpretation on the petrogenesis of these rocks is only possible if more geochemical and petrographical data are available. It is not possible at this preliminary stage, with meagre data, to draw more wide and fruitful conclusions. Also more information are needed on geochemistry of ultramafic rocks which occur in this area. The detailed work on the mafic and ultramafic rocks of this area is under way.

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CHAPTER-VII

TECTONIC IMPLICATION

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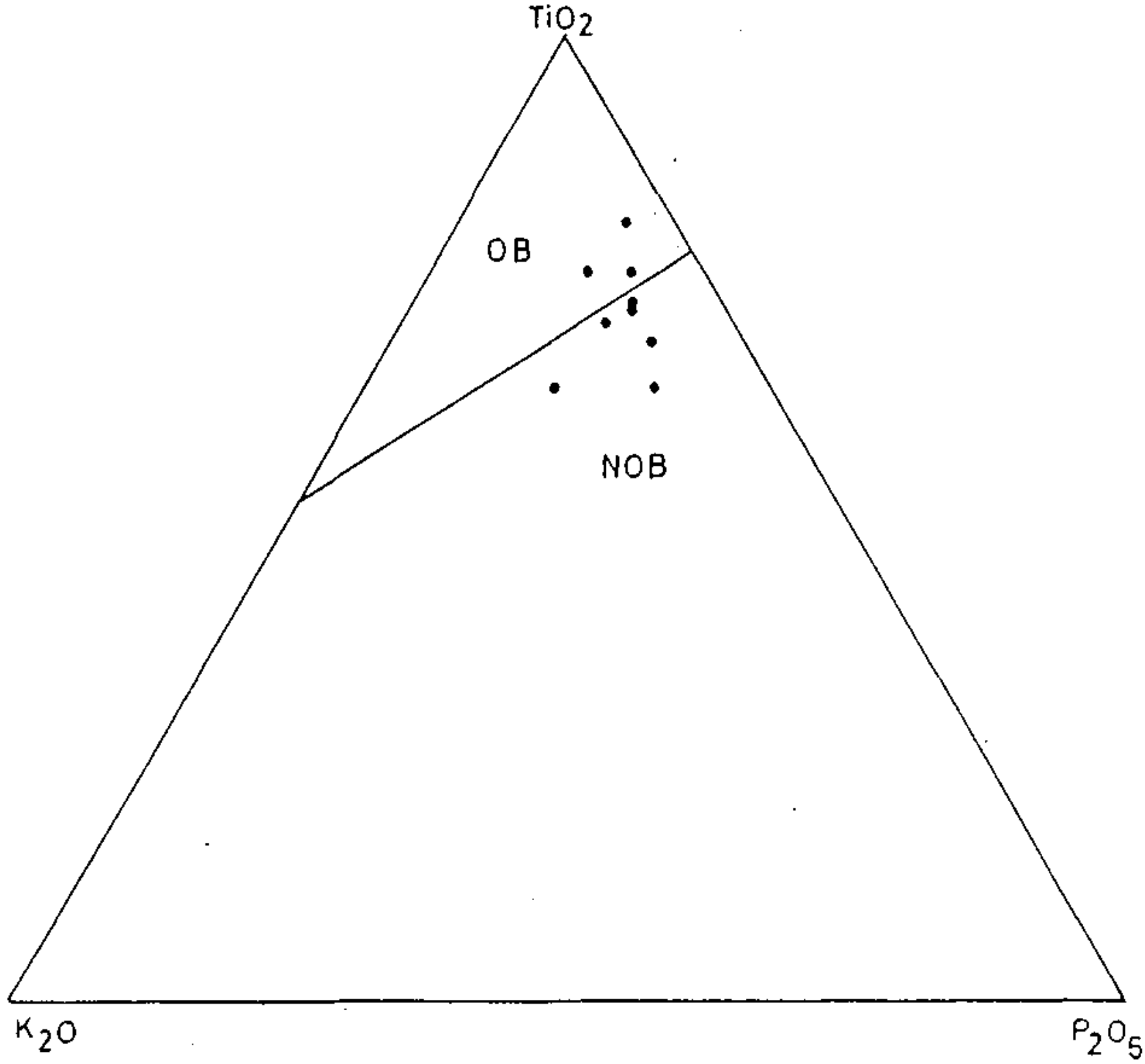
The vast exposures of basic/ultrabasic rocks of India are found, associated with different chronostratigraphic sequences. They range in age from 3500 Ma (Beckinsale et al., 1980) to 60 Ma (Srikantia et al., 1976) or even less, and thus provide ample opportunity to understand the compositional variations in the basic magmatism through time (Naqvi, 1979). The tectonic environment of magmatic eruptions may be inferred with the help of geochemical studies. Several successful attempts have been made to relate the chemical composition of basic volcanics to the nature of the crust and environment of magmatism. Jakes and White (1972) and Mohr (1972) have observed a direct correlation between the chemical composition of basic rocks and nature of the crust on which they erupted. These relations have been effectively used to interpret the nature as well as evolution of the earth's crust in different geological periods (Shaw, 1972; Naqvi and Husain, 1973; Naqvi et al., 1974 a, b; Rogers et al., 1974).

To know the tectonic environments of older lavas, the basement upon which the geological sequences were deposited, is an important factor. In the present area it is suggested that Ongarbira volcanosedimentary sequence was deposited on metamorphites of Chaibasa stage. The lithological and geochemical characters of metamorphites can be used to interpret the nature and strength of lithosphere in the Early Proterozoic period. Nowadays, because of wide acceptance of plate-tectonics, the tectonic environment of volcanic rocks is being interpreted in its light.

However, the applicability of present concept of plate tectonics in Precambrian period is a matter of controversy and debate. One group, believing in uniformitarianism, suggests that the operating global mechanism is continued since the formation of rigid crust in Archean (Windley, 1977, 1981; McWilliams, 1981). The second group does not believe in plate-tectonic process in Precambrian because of significant differences in physical conditions in the lithosphere and underlying mantle with geological time (Ramberg, 1967; Stephanson, 1976; Watson, 1976; Sutton, 1977; Schwerdtnev et al., 1978). The third group partially supports the theory of uniformatarianism and believes that the plate tectonics does not strictly follow uniformitarian principles and therefore, it initiated and operated in different ways as compared to present.

Many workers (Condie, 1972, 1973; Katz, 1974; Kroner, 1982) have invoked the plate tectonic concept for the Precambrian orogenies. The constituents of Ongarbira volcanics



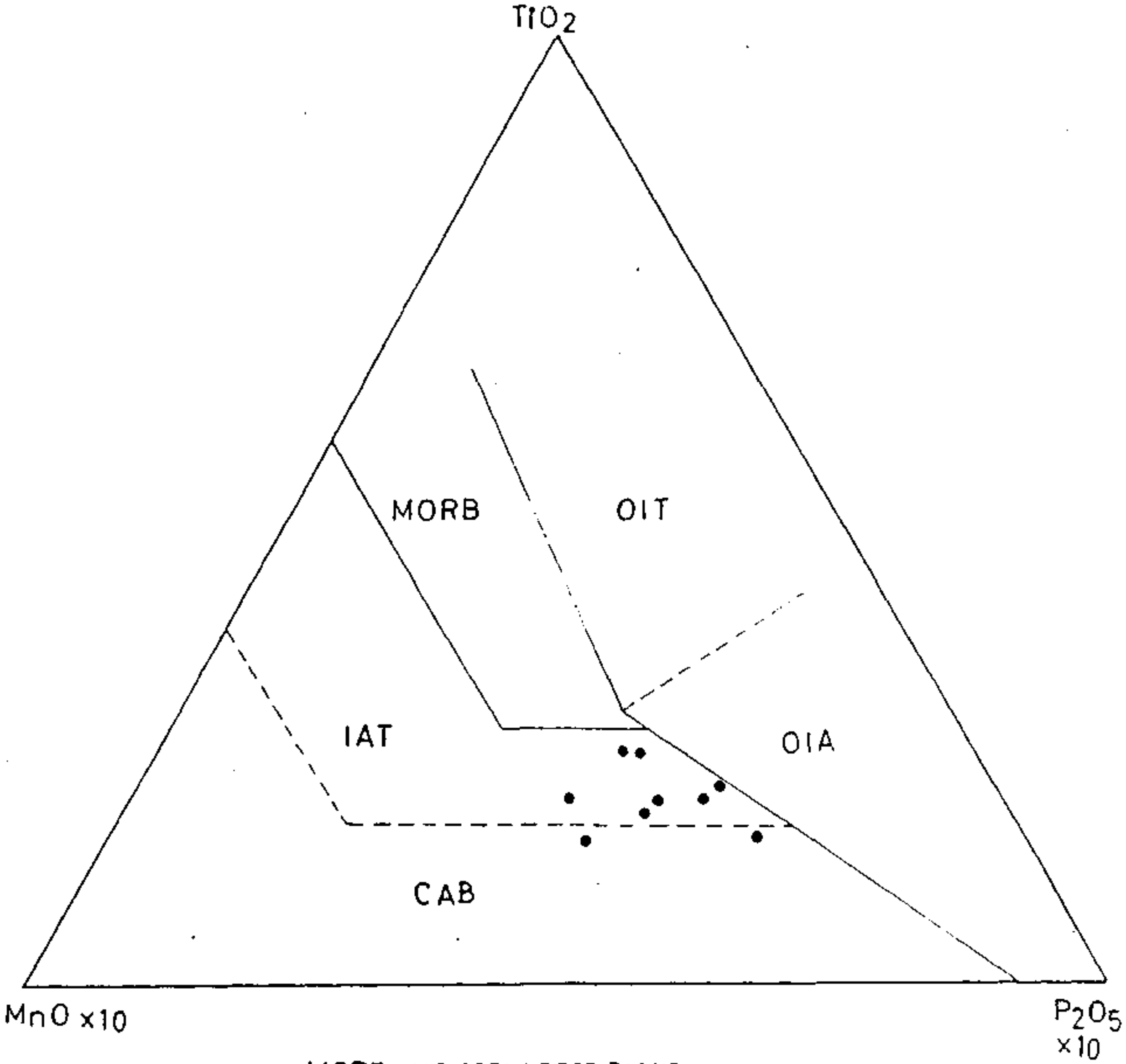
OB – OCEANIC BASALT
NOB – NONOCEANIC BASALT

Fig.25.

TiO_2–K_2O–P_2O_5, PLOT FOR ONGARBIRA VOLCANICS.

as discussed in previous chapters and plotted in SiO_2-FeO*/MgO, TiO_2-FeO*/MgO, FeO*-FeO*/MgO, Ni-FeO*/MgO, TiO_2-SiO_2 and Ti-Cr variation diagrams (Figs. 6, 7, 8, 9, 10, 11) show chemical affinity with oceanic basalt. FeO*/MgO ratio of basaltic rocks has been considered to be a significant feature in recognition of abyssal and island arc tholeiites (Miyashiro, 1975). It is suggested that ocean floor tholeiites possess FeO*/MgO value less than 2. The Ongarbira volcanics possess FeO*/MgO ratio less than 2 (avg. 1.21) which indicates their abyssal tholeiitic nature. Engel et al (1965) considered the concentration of K_2O as a criterion of distinguishing the tholeiites of various tectonic environments. He pointed out that ocean floor thole-iites bear K_2O content less than 0.2 per cent. The Ongarbira volcanics also appear as low K-tholeiites (avg. 0.16 per cent) which again indicates their ocean tholeiite affinity.

The TiO_2-K_2O-P_2O_5 variation diagram was proposed by Pearce et al (1975) to distinguish the oceanic and non-oceanic basalts. This diagram, based on immobile trace elements, has been proved more useful (Zeck and Morthorst, 1982). To see the magma types, the constituents of Ongarbira volcanics are plotted in TiO_2-K_2O-P_2O_5 diagram (Fig. 25) in which three samples fall above the discrimination line in ocean basalt field and remaining six samples appear below the discrimination line in non-ocean basalt field but most of them are generally close to discrimination line which indicates their transitional composition.



MORB MID OCEAN RIDGE BASALT
IAT ISLAND ARC THOLEIITE
CAB CALC ALKALINE BASALT
OIA OCEAN ISLAND ALKALI BASALT
OIT OCEAN ISLAND THOLEIITE

TiO_2 – MnO × 10 – P_2O_5 × 10, PLOT FOR ONGARBIRA VOLCANICS.

Fig. 26.

Recently Mullen (1983) has proposed TiO_2-MnO-P_2O_5 variation diagram to discriminate the basaltic rocks of different oceanic environments. This diagram is useful to identify five types of oceanic basaltic rocks i.e. Mid-Oceanic ridge basalts, island arc tholeiites, island arc calc-alkaline basalts, ocean island tholeiites and ocean island alkali basalts. To elucidate the tectonic environment of Ongarbira volcanics, MnO, TiO_2 and P_2O_5 contents (all in weight per cent) are plotted in this diagram (Fig. 26) which demonstrates an island arc tholeiite affinity. The eruption of these basic rocks in true oceanic condition has been contradicted by their association with shallow water sediments. The quartzovolcanic sequence suggests the deposition of these basic volcanics in shallow water basin.

Therefore, the plots of studied samples in different discrimination diagrams do not permit to conclude any particular tectonic environment in which these rocks were erupted. For this purpose it is necessary to collect more geochemical data on these basic volcanics as well as ultramafic rocks occurring in this area. The major element composition and immobile trace element contents along with field data can be used to draw some fruitful conclusions about the tectonic environment which existed at the time of eruption of these rocks. The study on geochemistry and field relationships of these rocks is underway for this purpose.

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SUMMARY AND CONCLUSIONS

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The Sahedba sedimentation around Ongarbira area in Singhbhum region is characterised by the presence of volcanic rocks (Ongarbira volcanics) which occur in the form of flows and their extrusive nature is evident from the presence of widespread pillow structures and fine to large vesicles on the surface. This volcanic activity has been considered to be of Middle Proterozoic period of 1700-1600 Ma. The Ongarbira volcanics have been folded, faulted and at some places metamorphosed up to green schist facies.

Microscopic examinationsof Ongarbira volcanics do not show any considerable mineralogical and textural variations. The primary minerals are pyroxene and plagioclase with opaques. The secondary minerals include actinolite, chlorite, calcite and quartz. The actinolite with plagioclase gives an appearance of microspinifex texture. In some samples primary sub-ophitic relationship between pyroxene and plagioclase crystals is also seen.

Nine most fresh representative samples of Ongarbira volcanics have been analysed for their major and trace elements.

To find out the alteration effect on the composition of Ongarbira volcanics, the Molecular Proportion Ratio (MPR) plots are employed. It appears that most of the elements have not suffered redistribution except Na_2O and K_2O. The redistribution of Na_2O and K_2O has also been supported by Na_2O/K_2O-Na_2O+K_2O variation diagram where all the samples plot in spilite field. However, in ACN and Na_2O-CaO diagrams these volcanics do not plot in spilite fields and this is because of their high CaO contents. When the chemical constituents of Ongarbira volcanics are plotted in SiO_2-FeO*/MgO, FeO*-FeO*/MgO, TiO_2-FeO*/MgO, Ni-FeO*/MgO diagrams, the Ongarbira volcanics appear as tholeiites with abyssal tholeiitic affinity. Their ocean floor tholeiitic affinity is also evident from SiO_2-TiO_2 and Ti-Cr discrimination diagrams.

High MgO content (range 8.20 to 11.70), CaO/Al_2O_3 ratio (0.80) and low K_2O and TiO_2 (0.9 per cent) contents of Ongarbira volcanics suggest their strong affinity with basaltic komatiites. To confirm this characteristic, various constituents of these volcanics are plotted in(Fe_2O_3+FeO+TiO_2)-Al_2O_3-MgO, CaO-Al_2O_3-MgO and Al_2O_3-(FeO*/FeO*-MgO) discrimination diagrams. In all these diagrams they occupy the field of basaltic komatiites. Therefore, it confirms them as basaltic komatiite which probably suffered spilitization during post magmatic period.

Before the emplacement of Ongarbira volcanics, olivine and some pyroxenes had been fractionated from the parent melt. The fractionation has been suggested by the positive relationship between Ni-MgO, Cr-MgO and Ni-Cr plots and depleted values of Ni, Cr and Co. It is suggested that the parent melt of Ongarbira volcanics was rich in olivine in the early stage and probably after partial melting of mantle the magma started rising from the zone of magma generation to shallow reservoir. During ascend the magma cooled up to the temperature, where olivine crystallised and settled down. The crystallisation of olivine might have been immediately followed by pyroxene which alongwith olivine fractionated from the melt. So the magma reaching to the surface was appreciably differentiated.

Though the Ongarbira volcanics are distinguished as ocean floor tholeiites in various discrimination diagrams, their association with quartzites and other shallow water sediments suggests their eruption in shallow water basin. The eruption of Ongarbira volcanics in transitional environment has been supported by TiO_2-K_2O-P_2O_5 plot.

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TABLE I

Major Oxides and oxide ratios of Ongarbira Volcanics

Sample No.	OB-1	OB-2	OB-3	OB-4	OB-5	OB-6	OB-7	OB-8	OB-9
SiO_2	47.66	50.67	48.87	47.89	49.79	49.47	51.05	49.87	45.30
Al_2O_3	10.50	11.20	11.40	10.80	9.98	10.20	10.60	10.79	11.29
TiO_2	1.32	1.24	1.22	1.33	0.84	1.03	1.41	1.31	1.32
Fe_2O_3	6.90	2.23	1.84	0.75	1.57	1.28	2.29	2.95	4.13
FeO	9.40	10.36	9.12	11.08	10.52	8.40	8.84	7.72	7.52
MgO	10.63	8.76	8.76	10.10	8.20	9.37	8.80	11.70	10.06
CaO	10.40	8.43	12.11	12.67	12.82	10.92	12.42	10.68	13.38
Na_2O	3.35	3.52	4.71	4.33	5.25	5.01	4.91	3.71	6.26
K_2O	0.15	0.13	0.19	0.09	0.09	0.08	0.14	0.17	0.39
MnO	0.20	0.25	0.20	0.25	0.25	0.17	0.18	0.18	0.16
P_2O_5	0.37	0.36	0.31	0.29	0.28	0.42	0.26	0.24	0.34
$FeO^{(t)}$	15.56	12.29	10.71	11.68	11.84	9.49	10.83	10.32	11.18
FeO^*/MgO	1.46	1.40	1.22	1.15	1.44	1.01	1.23	0.88	1.11
Fe_2O_3/FeO	0.73	0.22	0.20	0.07	0.15	0.15	0.26	0.38	0.55
CaO/Al_2O_3	0.99	0.80	1.06	1.17	1.28	1.07	1.17	0.99	1.19
Na_2O/K_2O	22.63	26.46	24.78	46.06	58.98	35.78	68.19	21.56	16.05
D.I.	60.53	58.97	55.58	53.94	59.59	50.81	55.85	47.69	53.66

TABLE II

C.I.P.W Norms of Ongarbira Volcanics

Sample No.	OB-1	OB-2	OB-3	OB-4	OB-5	OB-6	OB-7	OB-8	OB-9
Qrt.	-	-	0.06	0.06	-	0.06	-	-	-
Orth.	1.11	1.11	1.11	0.56	0.56	0.56	0.56	1.11	2.22
Ab.	28.29	29.87	20.43	14.15	19.39	27.25	25.68	28.30	11.00
An.	13.07	14.18	9.45	9.73	3.39	5.01	6.67	12.23	1.95
Ne	-	-	10.51	12.21	13.63	8.83	8.52	1.70	22.44
Diop.	28.72	20.46	39.81	42.04	48.17	37.64	43.29	31.39	50.26
Hyp.	0.73	19.02	-	-	-	-	-	-	-
Ol.	15.14	6.15	11.90	16.79	10.08	12.74	9.56	17.29	6.74
Mag.	9.98	3.25	2.78	-	-	1.86	-	4.18	-
Hem.	-	-	-	-	-	-	-	-	-
Ilm.	2.58	2.43	2.28	2.28	1.67	2.00	2.74	2.43	2.58
Ap.	1.00	1.01	0.67	0.67	0.67	1.01	0.67	0.67	0.67

TABLE III

Range of Variation and average oxides (weight percent) of Ongarbira Volcanics

Oxides	Range Minimum	Range Maximum	Average
SiO_2	45.30	51.05	48.95
Al_2O_3	9.98	11.40	10.75
TiO_2	0.84	1.41	1.21
Fe_2O_3	0.75	6.90	2.66
FeO	7.52	11.08	9.22
MgO	8.20	11.70	9.59
CaO	8.43	13.38	11.54
Na_2O	3.35	6.26	4.56
K_2O	0.07	0.39	0.16
MnO	0.16	0.25	0.20
P_2O_5	0.24	0.42	0.32

TABLE IV

Trace Elements (ppm) and Elements Ratios of Ongarbira Volcanics.

Sample No.	OB-1	OB-2	OB-3	OB-4	OB-5	OB-6	OB-7	OB-8	OB-9
Ni	74	74	72	77	93	90	102	109	105
Cr	80	90	98	102	100	95	109	119	140
Co	13	15	17	12	15	17	17	18	19
Rb	8	9	9	7	6	4	8	6	2
Sr	68	46	54	85	45	91	64	167	90
Ba	124	170	196	114	152	156	156	184	165
Cu	56	74	134	47	173	141	69	182	182
Li	30	102	99	94	21	49	36	203	107
Zn	73	136	60	99	60	85	70	88	52
Ni/Cr	0.72	0.65	0.59	0.63	0.76	0.87	0.93	0.91	0.75
Rb/Sr	0.12	0.20	0.17	0.12	0.13	0.04	0.13	0.04	0.02

TABLE V

Range of Variation and Average Trace Elements (ppm) of Ongarbira Volcanics.

Traces	Range Minimum	Range Maximum	Average
Ni	72	109	88
Cr	80	140	117
Co	12	19	16
Rb	2	9	7
Sr	45	167	79
Ba	114	196	157
Cu	47	182	118
Li	21	203	82
Zn	52	136	80

TABLE VI

Average major oxides (wt %) and trace (ppm) elements composition of Ongarbira Volcanics compared with other basic rocks.

Sample No.	1	2	3	4	5	6	7	8	9
SiO_2	48.95	46.03	52.20	50.20	49.50	49.80	51.10	50.20	50.30
Al_2O_3	10.75	13.99	12.53	15.50	15.20	16.00	16.10	17.70	14.30
TiO_2	1.21	0.61	0.71	0.94	1.49	1.50	0.83	1.00	2.20
Fe_2O_3	2.66	1.82	2.68	1.63	2.80	2.00	3.00	3.90	3.50
FeO	9.22	9.35	10.63	9.26	9.17	7.50	7.30	6.30	9.30
MgO	9.59	12.77	7.06	7.53	6.82	7.50	5.10	5.40	5.90
CaO	11.54	9.97	8.95	11.60	8.79	11.20	10.80	9.80	9.70
MnO	0.20	0.17	0.22	0.22	0.18	0.17	0.17	0.20	0.20
Na_2O	4.56	1.10	2.83	2.15	2.70	2.80	2.00	2.70	2.50
K_2O	0.16	0.10	0.72	0.22	0.69	0.14	0.30	0.90	0.80
P_2O_5	0.32	-	0.12	0.10	0.17	0.20	0.15	0.20	0.16
Ni	88	405	183	140	125	100	25	50	100
Cr	117	-	750	490	250	300	50	50	100
Co	16	102	27	52	55	32	20	40	40
Rb	7	20	-	-	-	-	-	-	-
Sr	79	25	83	100	190	135	225	300	350
Ba	157	28	150	80	90	11	60	100	200
Cu	118	121	62	110	100	70	80	80	90
Li	82	-	-	-	-	-	-	-	-
Zn	80	-	-	80	120	75	80	80	90

1. Average analyses of 9 samples of basaltic Komatiites, Ongarbira volcanics, India.
2. Average analyses of 11 samples of Dalma metavolcanics, India.
3. Average analyses of 6 samples of Dhanjori lava, India.
4. Average analyses of depleted Archean tholeiites.
5. Average analyses of enriched Archean tholeiites.
6. Average analyses of Mid-oceanic ridge basalts.
7. Average analyses of Island arc tholeiites.
8. Average analyses of calc-alkaline tholeiites.
9. Average analyses of continental rift tholeiites.

TABLE VII

Average major oxides (wt %) and trace (ppm) elements composition of Ongarbira Volcanics compared with basaltic Komatiites of different provinces of the world

Sample No.	1	2	3	4	5	6	7	8
SiO_2	48.95	49.15	45.39	52.35	50.36	50.59	49.85	50.09
Al_2O_3	10.75	12.00	11.03	12.39	11.23	12.40	12.60	9.29
TiO_2	1.21	1.21	1.05	0.19	0.60	0.66	1.08	1.08
Fe_2O_3	2.66	3.19	-	1.78	-	11.55	13.09	-
FeO	9.22	9.33	13.66	7.00	9.13	-	-	12.98
MgO	9.59	12.66	15.37	14.11	13.20	12.05	11.37	11.60
CaO	11.54	9.32	10.93	9.11	8.26	10.77	9.95	12.46
MnO	0.20	0.26	0.18	0.18	-	0.21	0.21	0.27
Na_2O	4.56	2.34	0.96	2.35	2.50	2.44	1.88	1.88
K_2O	0.16	0.08	0.25	0.86	0.03	0.09	0.24	0.19
P_2O_5	0.32	0.24	-	0.05	0.03	0.05	0.06	0.06
Ni	88	197	671	298	-	306	220	311
Cr	117	1074	1886	858	-	1247	1267	926
Co	16	113	64	-	-	-	-	-
Rb	7	7	7	-	-	2	10	-
Sr	79	174	120	-	152	83	138	-
Ba	157	70	51	-	-	85	98	-
Cu	118	152	-	-	-	-	-	-
Li	82	144	-	-	-	-	-	-
Zn	80	12	-	-	-	-	-	-

1. Average analyses of 9 samples of basaltic Komatiites, Ongarbira Volcanics, India.
2. Average analyses of 10 samples of basaltic Komatiites, Debari Volcanics, India.
3. Average analyses of 6 samples of basiatic Komatiites,Kolar Schist belt,Karnataka, India.
4. Average analyses of 2 samples of basaltic Komatiites,Betscove,Newfoundland.
5. Average analyses of 3 samples of basaltic Komatiites, Destor Quebec.
6. Average analyses of 3 samples of basaltic Komatiites,Munro Township basalt Cycle III
7. Average analyses of 20 samples of basaltic Komatiites,Munro Township basalt Cycle I
8. Average analyses of 4 samples of basaltic Komatiites, Minnesota, Canada.

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